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THE TREATMENT

OF

INFANTILE PARALYSIS

LOVETT

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WITH 113 ILLUSTRATIONS

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TO THE

ANONYMOUS DONOR

WHOSE GENEROSITY MADE POSSIBLE THE

STUDY AND TREATMENT OF INFANTILE PARALYSIS IN VERMONT

AND TO THE

STATE BOARD OF HEALTH

WHICH SO EFFECTIVELY CARRIED OUT THE

DESIGN OF THAT DONOR

PREFACE

The great prevalence of infantile paralysis in America since 1907 has not only directed the attention of the medical profession to the disease in a very practical way, but has led to a rapid advance in our knowledge of the affection and of its treatment. Indeed so rapid has been this progress, particularly on the therapeutic side, that it has not had time to find its way into text-books, but exists almost wholly in the fugitive periodical literature.

It is to meet the situation just described that this book has been written and it is concerned wholly with treatment except for a short introductory chapter dealing with other aspects of the disease in their bearing on treatment. This limitation was adopted because my experience has been chiefly in this department and because conditions are not yet sufficiently settled with regard to pathology, etiology, transmission, etc., to make it possible to write a book with any promise of permanence which should deal with the whole subject.

The aim has been to present a practical, plain and perhaps rather elementary statement of the various therapeutic measures which I believe to be the soundest and best, and although I have not hesitated to quote from the work of others the personal point of view has been emphasized.

It has seemed best to discuss the question of the operative treatment of the affection in a comprehensive way but not to attempt to write an operative surgery. In this section my personal experience is responsible for my comments on the relative value of the different operations.

It has seemed desirable also to dwell at some length on the subject of muscle training because all experienced surgeons are today agreed that the operative treatment of infantile paralysis should not be undertaken until at least two years after the onset and during these two years, when the most rapid progress is to

be made, the treatment must needs be a non-operative one. As muscle training in my opinion constitutes the most important of the early therapeutic measures it has been somewhat emphasized. The material for the chapter on this subject has been furnished by my senior assistant in private practice, Miss Wilhelmine G. Wright, who has for some years devoted practically her whole time to this department of physical therapeutics and who has already published an article on the subject. I am greatly indebted to her for formulating for me the exercises and tests. Illustrations of some of the tests and exercises have been given with a view of making the text clearer.

It is impossible for me to acknowledge my indebtedness to the many who have helped me in my work, directly and indirectly. The work in Vermont was done in connection with laboratory work under the charge of the Rockefeller Institute of New York and to Drs. Simon Flexner and Harold L. Amoss of that institution I am greatly indebted for much advice. To my colleagues in the Physiological Department of Harvard University and in the Children's Hospital of Boston I am under obligation for assistance in many directions always willingly given. I owe very much also to the State Board of Health of Vermont not only for the opportunity to study the great amount of clinical material in that state but for their continued coöperation and advice and interest at all times. This obligation I have attempted to acknowledge in part by dedicating to them this book. To the many others who have helped me I offer my best thanks.

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TREATMENT OF INFANTILE PARALYSIS

CHAPTER I

PATHOLOGY—SYMPTOMS AND TYPES—MORTALITY—DIAGNOSIS—PROGNOSIS

The name infantile paralysis is used in this book to describe the affection under discussion because of the names in common use it seems the least objectionable. The name anterior poliomyelitis is incorrect for the reason that our better knowledge of the pathology has shown the cerebrum as well as the cord to be generally involved. The correct pathological name would be anterior poliomyeloencephalitis, which of course is impossible as a descriptive term. The name Heine-Medin disease proposed by Wickman offers no advantages, and has not been much used, while the names essential paralysis of children, teething paralysis and the like are obsolete. The name infantile paralysis does not correctly describe the affection when it attacks adolescents and adults, but on the whole it seems the most available for general use.

Infantile paralysis has in the last few years assumed a special importance on account of its increased frequency in America, as well as, to a less extent, its greater prevalence in certain foreign countries.[1] Although the disease was recognized and described by Heine in 1840,[2] it is only since 1907[3] that it has become a serious problem in America. In that year a great epidemic occurred in New York City, followed by a widespread prevalence throughout the United States and Canada,[4] so that now every year leaves behind it thousands of victims.

[1] Haglund Barnförlamnings foljderna och Devas Behundling, Stockholm, 1913.

[2] Warner: "Die Heine Medin Krkt," Leipzig, Diss. Halle, 1913.

[3] "Epidemic Polyomyelitis," Report of Committee, etc. N. Y., 1910.

[4] "The Occurrence of Infantile Paralysis in the U. S. and Canada," "Am. Jour. of Dis. of Children," August, 1911.

With this increased incidence of the disease there has come a new and better knowledge of its pathology, and especially of its treatment, which will be considered here. But as any sound treatment must be based on pathological data, it becomes important first to consider very briefly the pathology, in so far as it bears on treatment.

PATHOLOGY[1]

Infantile paralysis is a general infection, the results of which are most marked in the nervous system. In the nervous system at autopsy the meninges are found to be edematous and injected and there is a slight increase in the amount of cerebrospinal fluid. The brain and cord are edematous, and this is especially noticeable in the gray matter of the cord, which is darker than normal and often projects above the cut surface. Minute hemorrhages can generally be distinguished.

It seems probable that the infection enters the body from the upper respiratory tract, but once entered it evidently does its damage by means of circulating in the blood-stream. The first change in the pathological process is an acute insterstitial meningitis, usually most marked on the anterior surface of the spinal cord. In the cord itself there occurs a hyperemia, and a collection of small round cells in the lymph spaces surrounding the vessels. In many places the cells are so numerous that they press on the lumen of the vessel and exert a mechanical effect in obstructing the circulation. Minute or extensive hemorrhages occur, and there is an extensive edema.

These three factors, cellular exudate, hemorrhages and edema, appear to be the primary reaction of the nervous system to the virus of infantile paralysis. Because the virus reaches the nervous system through the blood-stream, the cervical and lumbar enlargements of the cord are most often affected, and the anterior horns more often than the posterior or the white matter, because in these regions the blood-supply is most

[1] This pathological information has been largely taken from the monograph of Peabody, Draper and Dochez. Rockefeller Institute, New York, 1912 and from the article by Flexner, Clark and Amoss, "Jour. of Exp. Med.," 1914, No. 2.

abundant. Although the process by which the vascular lesions affect the nerve cells is in large measure a mechanical one, it is impossible to exclude the fact that the virus may exert some directly toxic action on these cells, but whether or not this is the case, much of the trouble is to be explained by the circulatory disturbance and the exudate. The damaging effects therefore are to be attributed in part to direct pressure on the nerve cells of hemorrhages, edema and exudate, to which must be added the anemia following the constriction of the blood-vessels and in addition to this may be the direct toxic action of the virus itself on the nerve cells. On account of this pressure and anemia the nerve cells degenerate, and if the hemorrhage and exudate are absorbed soon enough the cells may recover function, but if the unfavorable conditions have been prolonged too long or are excessive, the nerve cells may go on to complete degeneration.

In addition to changes in the spinal cord it is very important to note that the same sequence of changes, vascular disturbance, and subsequent degeneration of the nervous elements, is found to a less degree in the brain, medulla and pons, the two latter showing some slight degree of involvement in most cases and frequently a marked cellular exudate and many hemorrhages. It is often difficult to reconcile the clinical symptoms which are referable to lesions of the pons with the actual autopsy findings.

The posterior root ganglia are practically always involved by lesions similar to those in the cord itself, and in experimental pathology this is the first step in the process. It is probable that the lesions in the sensory ganglia may to a greater or less extent account for the pain and tenderness which are almost constant features of the acute stage of the disease.

The terminal stage in the pathological changes is represented by the replacement of the motor cells by cicatricial tissue, with shrinking of the whole anterior horn in severe cases. The destruction of spinal cells in any center naturally represents a loss of function of those cells, but the connections between the bundles of motor cells and the connections between muscles and the motor centers are so free and so manifold that unless the destruction has been very extensive, the possibility remains of

establishing new connections between the motor cells and muscles.

The changes which are found in other organs in infantile paralysis are less striking than those of the nervous system, but are practically as constant, being shown as an extensive involvement of the lymphoid tissue and of parenchymatous organs. In the latter cloudy swellings are usually met with, not unlike those of typhoid fever.

In short, it must be remembered that infantile paralysis is a general toxemic process which affects organs throughout the body, but which apparently acts mildly, and on the other hand it is characterized by lesions in the spinal cord which occasionally prove fatal by involvement of the nerve cells controlling respiration; these changes generally lead to a greater or less impairment of motor function of certain of the cells controlling muscular action, most often in the legs. The great tendency toward spontaneous repair in this disease is explained by the pathology, which shows also why partial paralysis is so much more common than total.

SYMPTOMS

It will be necessary to summarize the symptoms in so far as they bear on the question of treatment. The symptoms are what one would expect from a consideration of the pathology—a scattered and widespread poliomyelo-encephalitis with meningeal complications. The clinical manifestation is a similarly widespread and scattered motor paralysis or weakening.

There is, in the great majority of cases, nothing characteristic about the acute onset. The symptoms are in general those of an acute infection. In many instances, however, gastro-intestinal symptoms predominate, while in others those referable to the respiratory tract are the most marked. Sweating, marked nervous irritability and general hyperesthesia are present in many instances before the onset of the paralysis, but they are not at all constant. Their presence points toward this disease, but their absence does not count against it.

The great majority of all cases are of the familiar and long

recognized type to be briefly discussed later, but there are variations in the disease described by Wickman[1] as types, in which the symptoms are not of the usual kind, and this description has aided us in recognizing the multiform character of the disease. Most of these types, as for instance, the ataxic form, are uncommon to say the least, but however uncommon some of these types may be, a great impetus was given to the intelligent study of the disease by Wickman's classification, and it was recognized that unusual localizations of the disease occasioned unusual symptoms.

Wickman's classification is as follows:

1. Ordinary spinal paralysis; anterior poliomyelitis.
2. Progressive paralysis, usually ascending, less often descending; Landry's paralysis.
3. Bulbar paralysis; polio-encephalitis of pons.
4. Acute encephalitis; giving spastic mono- or hemiplegia.
5. Ataxic type.
6. Meningitic type.
7. Polyneuritic (multiple neuritis) type.
8. Abortive type.

This classification is, however, objected to[2] as being complicated and based neither on pathological anatomy nor clinical symptomatology, and on the ground that the so-called types are not types but variations in symptomatology.

The classification of Müller[3] is simpler: (1) The spinal form, (2) the bulbar form, (3) the cerebral form, and (4) the abortive cases. Peabody, Draper and Dochez advocate a simpler classification still: (1) Abortive, (2) cerebral, where involvement of the upper neurone causes spastic paralysis, and (3) the bulbo-spinal group, where there is a lesion of the lower neurone with flaccid paralysis.

The fact is that a diffuse and variable process, by affecting different parts of the nervous system, causes different symptoms, and that no one classification will satisfactorily cover

[1] "Die Akute Poliomyelitis," etc., Berlin, 1911.

[2] Peabody, Draper and Dochez: Monograph No. 4, Rockefeller Institute, 1912.

[3] Müller: "Die Spinale Kinderlähmung," Berlin, 1910.

all cases. The references refer to unusual variations in the symptoms.

Müller: "Münch. Med. Wchsft.," Jan. 23, 1912.
Colliver: "Journ. A. M. A.," Mar. 15, 1913.
Wachenheim: "N. Y. Med. Journ.," Nov. 8, 1912.
Frissell: "Journ. A. M. A.," LVI, No. 9.
Koplik: "Am. Journ. Med. Soc.," June, 1911.
Batten: "Journ. A. M. A.," LXII, No. 15, p. 1200.
Pearson: "Birmingham Med. Review," Apr., 1910, p. 148.

An attack apparently confers immunity although one or two instances have been reported where a second attack seems to have occurred.

Ordinary Spinal Type.—It is unnecessary to take up in detail the symptoms of this, the common type, long recognized and described, but a summary of its features should be given. After an acute onset of greater or less severity a motor paralysis appears, reaching its maximum in the following period after the attack:[1]

	Cases	Per Cent.
Same day	95	16.12
One day	93	15.78
Two days	103	17.49
Three days	98	16.63
Four days	58	9.84
Five days	22	3.73
Six days	51	8.65

From an analysis of 589 cases.

Early symptoms frequently seen are feverishness, drowsiness, sweating, often gastro-intestinal symptoms, stiffness in the neck and back, difficulty with micturition or defecation.[2] Sore throat, delirium and convulsions are other occasional early symptoms.[3]

The onset of the disease is accompanied by tenderness in the great majority of cases, which tenderness persists for from one week to two or three months and leads to many diagnostic errors.

[1] "Infantile Paralysis," R. W. Lovett and M. W. Richardson, "Am. Jour. of. Dis. of Children," December, 1911, p. 369.

[2] F. R. Fraser: "Clinical Observations on Ninety Cases," etc., "Am. Jour. Med. Sci.," July, 1914.

[3] Lovett and Richardson: "Am. Jour. of Dis. of Children," December, 1911.

Following the development of the paralysis comes a stationary period, after which begins a spontaneous improvement in muscle power. This was formerly thought to last for about six months, but later observation has shown that it is by no means ended at the end of one year (Vermont figures). The final paralysis is, however, always less than the initial if the patient lives.

The paralysis is more often partial than total,[1] 1,452 affected muscles, 416 totally paralyzed, 1,136 retaining some degree of contractility (about 2.5 to 1). Estimated by the muscle-testing apparatus, to be spoken of later, which deals more with muscle groups and which detects more slightly affected muscular action, the proportion was about 9 to 1, 958 partially paralyzed groups and 111 totally paralyzed.

Distribution and Severity.—*Location.*—In 251 Vermont cases of all ages and of all durations since the attack, none, however, of less than two months, a careful personal examination gave the local distribution shown in the table. In 985 cases from the Massachusetts figures collected from the physicians' reports dealing with both acute and subacute cases, this class being naturally less closely and accurately observed than the Vermont cases showed slightly differing figures which are added for comparison. The two groups agree fairly well in showing that the affection of one leg is the commonest type, followed by that of both legs.

	Vermont Cases	Massachusetts Cases
1 leg	95	324
2 legs	73	272
1 arm	21	84
2 arms	4	23
1 leg, 1 arm	16	143
2 legs, 1 arm	14	...
1 leg, 2 arms	4	10
2 legs, 2 arms	14	129
	251	985

The accompanying table gives the number of total paralyses of each muscle, the number of partial and total paralyses, and

[1] R. W. Lovett: "The Treatment of Infantile Paralysis," "Jour. A. M. A.," June 26, 1915.

the proportion of total to partial in each. These figures were obtained by recording the power of voluntary contraction in the muscles and rest on careful personal observations.

TABLE I.—DEGREE OF AFFECTION OF INDIVIDUAL MUSCLES

Muscle	Number Paralyzed	Number Partial	Number Complete	Proportion of Partial to Total
Adductors	68	52	16	3·2:1
Gluteals	133	106	27	3·9:1
Flexors of hip	81	63	18	3·5:1
Quadriceps	152	119	33	3·6:1
Hamstrings, outer	97	66	31	2·7:1
Hamstrings, inner	95	73	22	2·7:1
Gastrocnemius	128	88	40	2.2:1
Tibialis anticus	119	53	66	0.8:1
Peroneals	96	40	56	0.7:1
Deltoid	57	45	12	3·7:1
Trapezius	49	42	7	6.0:1
Infraspinatus	17	8	9	0.9:1
Pectoralis	29	22	7	3·1:1
Biceps	31	24	7	3·4:1
Triceps	28	22	6	3·6:1
Abdominal	79	64	15	4·3:1
Latissimus dorsi	49	40	9	3·4:1
Spinal	40	36	4	9·0:1
Flexor carpi ulnaris	16	12	4	3·0:1
Flexor carpi radialis	16	11	5	2.2:1
Extensor carpi ulnaris	19	14	5	2.8:1
Extensor carpi radialis	18	13	5	2.6:1
	1,417	1,021	4 02	

The main facts are that the quadriceps, gluteals and gastrocnemius lead in frequency, and that paralysis of leg muscles is much more frequent than of arm muscles. Paralysis of the adductor of the thumb is extremely common. Abdominal paralysis existed in more than half of all the cases (seventy-nine), and affection of the muscles of the spine in more than a quarter (forty). The latter points have a distinct bearing on the occurrence of scoliosis, and indicate, apparently, that such affections are more common than had been supposed. The cases of abdominal paralysis were always symmetrical with

two exceptions, one right and one left. This paralysis may occur as the only perceptible one in the entire muscular system. When associated with paralysis of other parts, the association was always with leg muscles.

The tibialis anticus and gastrocnemius are the leg muscles most commonly found to be affected by themselves without paralysis occurring elsewhere in the body. Of the former muscle, there were five cases of paralysis, of the latter, three. Deltoid paralysis may occur alone in the arm.

Fraser[1] has called attention to the frequency of involvement of the facial muscles in cases of the ordinary type of paralysis affecting the limbs, a fact generally not recognized. In a series of ninety cases thirty-one showed involvement of facial muscles. In five cases the facial muscles alone were involved while in the other twenty-six other parts of the body were also affected.

In the lower extremity analysis shows that the paralysis is severest in the foot, next most severe at the knee and least severe at the hip while in the arm it is severest at the shoulder, lighter at the elbow and least severe in the hand.[2]

With regard to distribution of the motor disturbance, the more exact the method of examination the more will the clinical phenomena be found to correspond with the modern pathological findings from experimental and human post-mortem data. The muscle test to be described (page 152) shows that the distribution of the paralysis is more widespread than ordinarily supposed and confirms the observation that the loss of motor function is much more often partial than total. The conception of the disease from these findings would rather indicate a general infection accompanied by a widespread and irregular loss of power, in most muscles of a mild grade. This corresponds to the modern pathological findings of a generally distributed myelitis accompanied by punctate hemorrhages as well as by more serious lesions through extensive areas in the cord and pons and an accompanying meningitis.

Given the paralysis of one muscle or muscular group it can-

[1] "Am. Jour. Med. Sci.," July, 1914.

[2] R. W. Lovett: "The Treatment of Infantile Paralysis," "Jour. A. M. A.," June 26, 1915.

not be inferred that any other muscle or muscular group is necessarily paralyzed or not paralyzed in connection with it and no inferences can be drawn. One fact, however, is clear from 13,000 muscular observations made on 177 patients by the muscle test to be spoken of later, namely, that the paralysis is generally more widely distributed than would be supposed from a casual examination. Paralysis of the gastrocnemius muscle, *e.g.*, is frequently spoken of as a clinical condition but really paralysis of this muscle alone occurred only twice in 177 cases carefully measured, other muscles being weakened also. When one leg is involved it is common to find weakening of some of the muscles of the other leg. When both legs are affected it is not uncommon to find some weakening of some of the arm muscles. This fact is of great importance in formulating treatment. In thirty-two cases of the Vermont series taken consecutively from the files for this analysis the following data were observed: Ten cases had been classed by manual examination as having only one leg affected; by the muscle test nine of these showed weakness of muscle groups in the other leg. In eighteen other cases of paralysis of more than one limb examination showed unsuspected involvement elsewhere in ten (55 per cent.).

Deformities develop during the disease in certain cases and will be discussed under three heads later on: (1) the prevention of deformity, page 35; (2) the causes and varieties of deformity, page 53; (3) the mechanical and operative correction of deformity, page 75.

Later on the *reflexes* are diminished or absent in affected muscles, and the reaction of degeneration is present to the electrical current in paralyzed muscles. *Sensation* is ordinarily stated to be unimpaired but the modern pathology makes this seem unlikely because the posterior root ganglion is generally the first part of the nervous system to be affected and because tenderness is generally present early. In a few cases of infantile paralysis, old and recent, tested by Prof. E. G. Martin[1] of the

[1] Martin, Porter and Nice: "The Sensory Threshold for Faradic Stimulation in Man," "Psychological Review," xx, 1913, p. 194.

Martin, Paul, and Welles: "A Comparison of Reflex Thresholds with Sensory Thresholds," "Am. Jour. of Psychology," xxvi, 1915, 428.

Harvard Medical School by his delicate electrical test for sensation, all showed a diminution of sensation over the affected limb. No more definite statement can be made at present beyond the one that sensation is probably affected if one examines with a sufficiently delicate test.

Disturbances of circulation occur in the severer cases accompanied by atrophy of bone and muscle and by retarded growth, the whole group being spoken of as trophic disturbances. During cold weather such limbs become cold and blue and subcutaneous areas of discolored tissue often occur which may break down and if they become infected cause indolent ulcers which repair slowly.

FIG. 1.—Trophic ulcer of the skin in a totally paralyzed leg. Occurring in cold weather.

Abortive Type.—The abortive type may next be taken up as second in importance. This type was originally described by Dr. C. S. Caverly[1] of Rutland, Vermont, as follows:

"It will be seen by these tables that six of these cases had no paralysis, as stated, but all of these had distinct rigidity of the spinal muscles, strabismus, or other symptoms referable to the nervous system, and are therefore included in this report."

Later this type was more fully described by Wickman.[2] It consists of an acute febrile attack not generally to be differentiated at the outset from the attacks followed by paralysis.

In general, abortive cases may be divided by their symptoms into the following types: (1) General infection, (2) symptoms of meningeal irritation, (3) cases with much pain like influenza, and (4) cases with marked digestive disturbance. The char-

[1] "New York Med. Rec.," Dec. 1, 1894.
"Jour. A. M. A.," Jan. 4, 1896.

[2] Wickman: "Die Akute Poliomyelitis, Heine Medinsche Krankheit," Berlin, 1911.

acteristic of the abortive cases is, however, that they are not followed by a frank paralysis. Some of them show a suspicious weakness during convalescence, but to our previous methods of examination no paralysis has been evident.[1] That many such cases would more often show a real local muscular weakening to a delicate quantitative examination of muscular power is the belief of the writer and some of his colleagues, and is supported by a case of apparently purely abortive paralysis examined with great care in Vermont, where gluteal weakness previously unsuspected was found. In a brother of this child, however, examination of the same sort made the second case appear purely abortive, as nothing abnormal was found a few months after the attack.

In such cases an immunity test may be made, where the diagnosis is of especial importance, by a lumbar puncture and the administration to a monkey of a dose of the virus mixed with the child's serum, in order to see if the child's serum gives immunity to the monkey against infection. If it gives such immunity the affection was clearly infantile paralysis. If it does not give immunity the child may or may not have had the disease.

It is undisputed that cases occur which are undoubtedly infections of this abortive type, that they are very common during epidemics, and that they are frequently unrecognized. Wickman found 25 to 56 per cent. of abortive cases in the total incidence of the disease, which figure he considered far too low, and he was supported in this opinion by Müller, who believes that the abortive cases would outnumber the cases of frank paralysis.[2]

According to Wickman's classification six other types remain. These may be summarized briefly from his point of view as follows:

Progressive Type.—In this type the paralysis usually appears first in the legs, and gradually extends upward. In rare instances it appears first in the arms, extends downward

[1] E. A. Sharp: "Abortive Forms and Pre-paralytic Stage of Acute Poliomyelitis," "Jour. Nervous and Mental Dis.," May, 1913.
[2] E. Müller: "Die Spinale Kinderlahmung," Berlin, 1910.

and finally upward to the muscles supplied by the medulla. It is probable that the great majority of the cases that have in the past been described under the term of "Landry's paralysis" really were examples of this type of infantile paralysis. When the paralysis reaches the external muscles of respiration, as it very often does, death is likely and usually occurs on the fourth or fifth day. The diaphragm is also sometimes involved. This form must not be confused with that in which death results from respiratory paralysis due to involvement of the centers of respiration in the medulla.

Bulbar Type.—Cases of this type have in the past been usually designated as polio-encephalitis superior or inferior, according to which of the cranial nerve nuclei were involved. The nuclei may be affected singly or in all possible combinations. The symptoms depend, of course, on the nuclei involved. The facial and abducens nerves are perhaps the most often affected. There may be paralysis of deglutition and of the muscles of the larynx. When the vagus is involved there are disturbances of respiration and of the cardiac action. In such instances, the respiration is often of the Cheyne-Stokes type and the prognosis is practically hopeless. Involvement of one or more of the cranial nerve nuclei is not very uncommon in connection with the ordinary spinal type of infantile paralysis. When this happens the resulting picture is a combination of the two types.

Acute Encephalitic Type.—This type was described by Strümpell many years ago under the term, "acute encephalitis of children," but it has only recently been recognized as a variety of the disease under consideration. The symptoms resemble those of acute meningitis, the deep reflexes are, as a rule, exaggerated and the paralysis is spastic. The diagnosis is usually impossible without lumbar puncture. The prognosis as to life is better than it would appear and that as to recovery from the paralysis much better than in paralysis due to other cerebral diseases.

The Ataxic Type.—Ataxia is a prominent symptom in a certain number of cases. In a few, it is the only nervous symptom; in others, it is associated with paralysis of the

cranial nerves and sometimes with a small amount of spinal paralysis. The ataxia is often distinctly of the cerebellar type.

The Meningitic Type.—Symptoms of meningeal irritation are not at all uncommon in the early stages of all types of infantile paralysis. These are so marked in many instances that they present the typical picture of meningitis. . Headache, rigidity of the neck and back, vomiting, tonic and clonic spasms, strabismus, Kernig's sign, delirium, coma and other signs of meningeal irritation may be present in any and all combinations. In such cases the diagnosis on the symptomatology alone is impossible before the appearance of the flaccid paralysis. Even then it is open to doubt, because flaccid paralysis may occur in meningitis, especially of the tuberculous type.

The Polyneuritic Type.—Pain is an especially prominent symptom in some instances. It is sometimes located in the joints, but is more often along nerve-trunks or indefinite in its distribution. It is usually most marked in the paralyzed parts. The pain and tenderness are sometimes marked enough to cause the paralysis to be entirely overlooked and a diagnosis of rheumatism or scurvy to be made.

The extremities are often held rigidly and all motion as vigorously resisted as possible, because of the pain caused This combination of rigidity and resistance is possible, of course, only when the muscles are partially paralyzed or when some of them are intact. The failure to appreciate the significance of this combination of flaccidity and spasticity not infrequently leads to errors in diagnosis during the acute stage.

MORTALITY

The death-rate was about seven or eight per hundred as the disease existed in Massachusetts, but no foreign statistics show as low a figure as this, being from 10 to 22 per cent. It must be remembered, however, that the death-rate will depend on the thoroughness with which cases are reported, and in Massachusetts there is reason to believe that the reporting of cases was unusually thorough. In persons older than ten, the mortality-rate is higher than between one and ten, and under one year the disease seems more fatal.

The mortality table is interesting as showing the difference between the foreign and American death-rate.

COMPARISON OF FOREIGN AND AMERICAN DEATH-RATE

	Year	Cases	Death	Mortality, Per Cent.
Caverly, Vermont	1894	132	18	14.5
Wickman, Sweden	1905	868	145	16.7
Leegaard, Norway	1905	577	84	14.5
Zappert, Austria	1908	266	29	10.8
Lindner and Mally, Austria	1908	71	16	22.5
Furntrat, Steiermark	1908	433	57	13.1
Krause, Germany	1909	633	78	12.3
Müller, Germany	1909	100	16	16.0
Peiper, Germany	1909	51	6	11.7
Eichelberg, Germany	1909	34	7	20.6
Massachusetts, U. S. A.	1907–1910	1,599	125	7.9
Vermont	1914	235	50	17.0

The mortality of cases in older children and in adults is higher than in other classes.

TABLE SHOWING HIGHER MORTALITY IN THE MORE ADVANCED AGES

	Age	Mortality, Per Cent.
Wickman	12 to 32	27.6
Leegaard	15 to 30	25.8
Furntrat	Over 15	25.5
Lindner and Mally	Over 11	50.0
Massachusetts, 1910	Over 10	20.0

DIAGNOSIS.

The diagnosis of infantile paralysis is rarely made before the appearance of the paralysis, and a surprisingly large number of cases are wrongly diagnosticated at this early period even when seen in the midst of an epidemic. The appearance of symptoms suggesting an acute infection in a young child in late summer especially in a region where the disease prevails is always suspicious. Particularly, is this the case if accompanied by sweating, nervous irritability and especially hyperesthesia. Under these circumstances an immediate lumbar puncture is warranted and forms our chief diagnostic support

at this time. The characteristics of the spinal fluid in this disease are as follows:

The fluid in the acute stage as a rule is clear and colorless and does not show great increase of pressure. In the first few days after the onset of symptoms it shows changes in the number of cells present or in the globulin content or in both in the majority of cases. The increase in cells is highest during the first week as a rule, and in a case of Fraser's[1] reached the figure of 1,221 per cubic millimeter. The number of cells diminishes rapidly, and in Fraser's cases was above normal in only 32 per cent. in the third week. The globulin reaction, however, is usually most marked during the third week, persisting as a rule into the fourth week, and it may be present for a longer period. The increase in cells is due almost invariably to mononuclear cells of various types, of which the lymphocytic is the most common. A high polymorphonuclear count was noticed in the very early stages. All the fluids reduced Fehling's solution. The spinal fluid examination may be of value in diagnosis not only in the pre-paralytic stages but in abortive cases.

The characteristics of the cerebro-spinal fluid in meningococcal, influenzal, and pneumococcic meningitis are so different from those in infantile paralysis that confusion with these conditions would hardly occur. Tuberculous meningitis, however, is more difficult to diagnosticate because the characteristics of the spinal fluid are much alike in the two conditions. In the former as a rule there are more cells but not always. There is generally more pressure in the spinal canal and the tubercle bacilli may be found in the fluid.

In the early stages the blood count shows a mild leucocytosis with a decided increase in the lymphocytes and a decrease in the polymorphonuclear leucocytes.[2]

The attack itself, apart from these characteristics, may resemble an ordinary gastro-intestinal attack, a common cold, influenza, the beginning of one of the exanthemata or other of the common acute affections of childhood. The appearance of

[1] Fraser: "Study of the Cerebro-Spinal Fluid in Acute Polyomyelitis," "Jour. of Exp. Med.," 1913, p. 242.

[2] Skoog: "Treatment of Acute Anterior Polyomyelitis," "Jour. A. M. A.," Nov. 19, 1910.

tenderness often marks the condition and leads to incorrect diagnosis; it must be remembered that tenderness is a routine symptom in the majority of cases.

When the paralysis has occurred, the diagnosis as a rule presents but little difficulty. It is a motor paralysis, or weakening, of erratic distribution, most marked in the legs. Reflexes are diminished or lost, the reaction of degeneration is present in the most severely paralyzed muscles, atrophy, retarded growth, coldness, and sluggish circulation supervene in the later stages in many cases. Atrophy of the thenar eminence is a frequent occurrence in infantile paralysis and at times throws light on the diagnosis of doubtful cases.

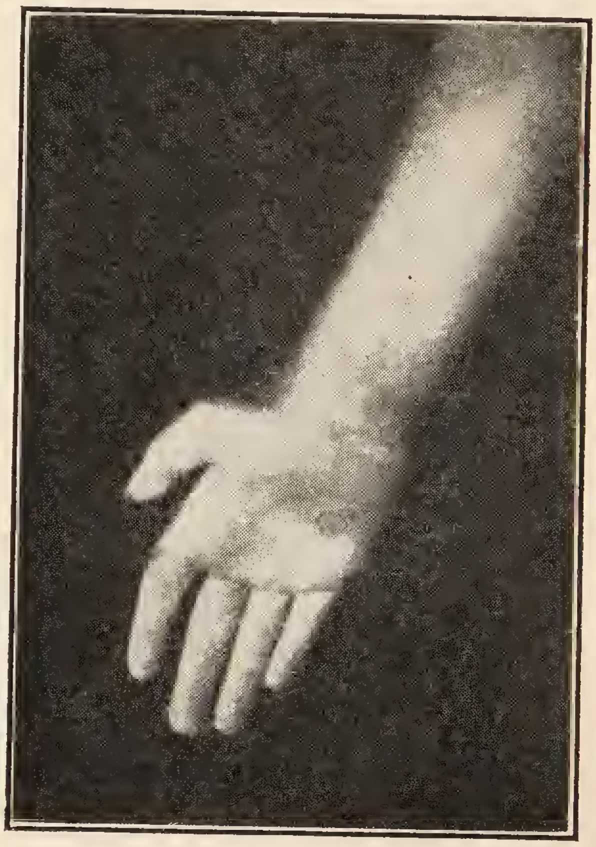

Fig. 2.—Atrophy of the thenar eminence.

But even when paralysis is developed the diagnosis is not always quite easy.

The difficulties occasionally attending the diagnosis of the affection may be illustrated by some personal cases. A boy with a fractured elbow, while the arm was in the splint, was seized with an attack of fever, and had increased pain in the elbow. When the splint was removed, the arm was found entirely paralyzed from the shoulder down, and on examination was found to be a typical case of infantile paralysis. A boy with a congenital deformity of the foot, a talipes equinus, came to the clinic with a history of having always been lame, but after a feverish attack being much lamer. Analysis of the case showed a mixture of congenital deformity and recent infantile paralysis. In one family two children of about the same age were brought, one with a typical cerebral hemiplegia of three years' duration, the other one with a typical infantile paralysis of an arm and a leg. The family had classed them both as the same condition. Two cases seen at the Children's Hospital

may be mentioned, one of a child with a congenital dislocation of the hip in one leg and infantile paralysis in the other, and another child with an obstetric paralysis of the arm on the right side existing from birth, and a subsequent infantile paralysis of the leg on the same side.

PROGNOSIS

The prognosis as to *life*, is expressed in the mortality table just given. From the age of ten upward the patient is more likely to die in the acute attack. Epidemics in some localities show great virulence. Death when it occurs in the acute attack generally occurs from involvement of the muscles or centers of respiration and is most common on the fourth or fifth day and is unlikely after the seventh day. Cases with paralysis of the upper extremity are more likely to die of respiratory involvement than cases with paralysis only of the lower extremities.

Paralysis of the intercostal muscles is not necessarily fatal although if recovered from, as a rule predisposing to attacks of bronchopneumonia later, but perfectly good health with freedom from respiratory troubles has been seen by the writer many years after the attack in patients who had no measurable chest expansion in attempted inspiration.

The prognosis as to *function* is a very practical matter and one on which the surgeon will be closely cross-examined by the parents and in the present state of our knowledge the man of experience will, in the early days of the disease, express himself with great reserve in this matter. In the acute stage it is particularly unwise to express a definite opinion as to the final function. On the whole, a severe onset is more unfavorable than a mild onset. The following figures were collected by Lovett and Lucas.[1]

Character of Onset		Character of Final Paralysis		
		Severe	Moderate	Mild
Severe	98	51	28	19
Moderate	84	25	44	15
Slight	31	2	10	19

[1] Lovett and Lucas: "Jour. A. M. A.," Nov. 14, 1908.

But in individual instances a severe onset may be followed by complete recovery or mild paralysis, and a very mild attack by severe and extensive paralysis.

In the acute attack, therefore, one must remember that on the whole, a mild onset is more favorable as to ultimate function than a severe one but that any statement beyond this as to ultimate function is unsafe unless the attack be extremely slight, in which case the outlook is more favorable. In all cases, however, after the onset a period of spontaneous improvement may be predicted beginning with or slightly before the disappearance of the tenderness and progressing to any point up to complete functional recovery.

This *spontaneous improvement* was formerly supposed to last for some six months but the Vermont study has shown that it continues much longer than this. In one case of four years duration 70 per cent. of improvement occurred in two months in muscles not being treated and 470 per cent. in the muscles treated by muscle training.

In the same study, seven cases had received no treatment at the end of one year and at this time in thirty-seven muscle groups tested twice in two months there was gain in nineteen groups and none in eighteen, a ratio of 1 to 1 of purely spontaneous improvement at the end of a year. We have as yet no figures to show how late purely spontaneous improvement lasts. Apparently the treatment of some of the affected muscles increases the spontaneous improvement in other affected muscles in the same individual which are not treated.[1]

As to *complete functional recovery*, it occurs much oftener than was formerly supposed. In 1911 an investigation was made of the condition of the cases in Massachusetts paralyzed in 1907.[2] This investigation was made by a competent orthopedic surgeon for the Massachusetts State Board of Health. Of the 234 cases paralyzed in that year twenty-two had disappeared, leaving 212 where the outcome was known. Of these cases fifty-seven were reported as having wholly re-

[1] Lovett and Martin: "Certain Aspects of Infantile Paralysis," "Jour. A. M. A.," Mar. 4, 1916.

[2] B. E. Wood: "Boston Med. and Surg. Jour.," Oct. 5, 1911.

covered (27 per cent.). These cases were not all personally seen but still the fact remains that all of them had made sufficiently good progress to be considered by the parents as cured. In some, function seemed normal but atrophy persisted, in others there was no atrophy. The following table deals with the matter:

		Per Cent.
Complete recovery without atrophy	16	28.1
Functional recovery with atrophy	21	36.8
Recovery with some hypertrophy	3	5.3
Recovery, presence or absence of atrophy unknown	17	29.8

Leaving out the last group, and averaging those in which the presence or absence of atrophy is known, shows that for every four functional recoveries without atrophy there were five with atrophy. When atrophy was present the maximum amount noted was as follows:

	Inches
Calf	1¾
Thigh	1¼
Arm	½
Forearm	¾

The severity of the attack in the recovered cases was classed as:

		Per Cent.
Severe	14	24.5
Moderate	9	15.9
Mild	28	49.1
Not noted	6	
Total	57	

The time of recovery was as follows:

One week or less	2
One week to one month	8
One to two months	8
Two to three months	5
Three to six months	10
Six to twelve months	9
One to two years	5
Two to three years	5
No data	5
Total	57

Through the first weeks after the onset the severest cases show but little return of power, tenderness is severe and lasts a long time, and the paralysis is widespread. In cases in which at the end of two months there has been but little gain, the outlook is not encouraging for very good function.

The question of prognosis arises most acutely in the stationary period in connection with treatment. The question of spontaneous improvement has been discussed and there

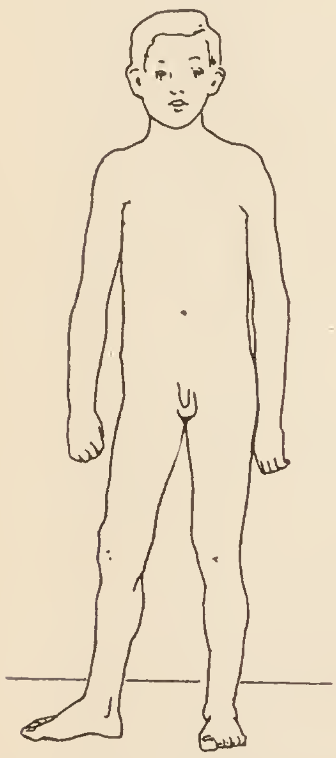

Fig. 3.—Outward rotation of right leg; quadriceps paralysis.

Fig. 4.—Talipes equinus of right foot and quadriceps paralysis of the right leg. The former locks the knee in extension when weight is borne upon the leg and makes it possible for the patient to walk without support.

remains the question of improvement under treatment. In a general way the outlook is better in the first year than later and the more voluntary power shown by the affected muscles the better the outlook for such muscles. It must be remembered that total paralysis is less common than partial and that the problem of strengthening weakened muscles by therapeutic exercises has made great strides in late years. Most untreated cases or badly treated cases are capable of marked or great improvement by treatment. The writer has never seen more than

two or three cases that could not be made to walk in some form or other and these cases were of the severest possible type—a really bedridden case of infantile paralysis should almost never occur. Deformities may have to be removed, and apparatus furnished to trunk and legs but locomotion is practically always

Fig. 5.

Fig. 6.

Fig. 5.—Gait in severe double paralysis of the quadriceps muscles. The patient presses back on both knees and bends forward to prevent knees from flexing.

Fig. 6.—Method of walking with a paralyzed right quadriceps. The knee is prevented from flexion by the pressure of the hand.

possible. There seems to be no time limit to the benefit to be derived from treatment, a case of the writer's of twenty-five years' standing who had never walked with the feet on the ground being most satisfactorily treated by braces which enabled her to walk with a cane.

With regard to the disability caused by various locations of the paralysis, the following facts may be borne in mind. A

complete paralysis below the knee with the thigh and hip muscles fairly sound, allows walking, but the foot is lifted high and the gait is awkward. Paralysis of the quadriceps whether the foot is paralyzed or not makes it impossible to bear weight on the leg without a brace or assistance from the hand unless (1) there is an equinus deformity in the foot, or (2) the knee becomes hyperextended, or (3) the patient learns to walk with the leg outwardly rotated, or (4) the patient learns to walk leaning forward at the waist, or (5) if with a weakened quadriceps the hamstring muscles remain strong. Paralysis of one gluteal muscle with the rest of the leg fairly sound causes a bad limp. The paralysis of both gluteals in connection with leg paralysis makes walking difficult and the asset of fairly good hip flexors and gluteals in a patient with paralysis of both legs may make the difference between being always dependent on crutches or walking without them. These statements, however, must be regarded as being only of the most general sort because the interdependence of muscles is such that no muscle acts singly and alone, but these statements roughly cover the requirements of standing and walking unaided, a most important question in formulating a functional prognosis.

Prognosis as to shortening will frequently be expected from the surgeon. It must be remembered that the amount of leg shortening except from dislocation of the hip is rarely great and an ultimate shortening of two inches would be exceptional; at times somewhat more than this occurs but it is rare. The important fact to remember in this aspect of the prognosis is that the amount of shortening is not necessarily proportionate to the degree of the paralysis, slight cases often being accompanied by much shortening and severe cases by moderate shortening. The shortening is due to the fact that the leg grows more slowly than the other and this retardation of growth is accounted for by the supposition that the so-called trophic centers of the cord are more affected in some cases than in others. There is nothing to show that the use of a brace seriously promotes shortening. On the one hand, the brace constricts the limb and restricts the activity of certain muscles

but as a brace is put on to allow walking and thus to promote function of the whole limb it cannot be assumed that its use would under these circumstances retard the growth of the leg, when it is remembered that without the brace the limb probably would not be used at all.

Effect of Treatment on the Prognosis.[1]—In the Vermont series of cases the chance of improvement under treatment by muscle training and restriction of exercise at the end of one year after the onset was found to be as follows: In a two months' period by means of the muscle test the chance of improvement in affected but not totally paralyzed muscles under expert daily treatment was 6 to 1; under supervised home exercises 3.5 to 1; with home exercises without supervision 2.8 to 1; while untreated affected muscles in these patients showed an improvement ratio of 1.9 to 1. Moreover, the outlook for muscles totally paralyzed at the end of one year seems better than supposed. Of forty-four totally paralyzed muscle groups in the Vermont series twenty-one (48 per cent.) developed demonstrable power at the end of two months, while in forty-four totally paralyzed muscular groups not receiving treatment, twelve (27 per cent.) developed demonstrable power in the same period.

As a concrete instance of the prognosis in a definite group of cases seen at a six months' interval who had received treatment by muscle training a quotation from an article[2] may be given bearing on cases seen by the writer in Burlington, Vt., in January, 1915 and July, 1915.

"Twenty-four cases: one had received no treatment and was no better, one was too unruly to examine and one was too young for accurate data. In the remaining twenty-one cases the improvement had been from slight to very great. The cases were all affected in the summer of 1914. The following changes were noted in muscles: (see page 25).

"The two most striking cases in the Vermont series were to be found in the Burlington group. A man of thirty-eight, at-

[1] Lovett and Martin: "Jour. A. M. A.," Mar. 4, 1916.
[2] Lovett and Martin: "Vermont Medicine," February, 1916.

	Partial Paralysis to Recovery	Total to Partial Paralysis
Deltoid	6	1
Pertoral	3	0
Trapezius	3	1
Triceps	1	0
Arm muscles	2	0
Forearm muscles	1	0
Bath muscles	5	0
Abdominal muscles	5	1
Quadriceps	1	2
Hamstrings	2	0
Gastrocnemius	4	0

tacked in August, 1914, was helpless and brought to the January clinic on a stretcher, and was with one exception the

Fig. 7.—Method of progression in a boy unable to walk, untreated. By treatment later enabled to walk with braces.

severest case seen in Vermont. In July he was earning his living by selling farm machinery in his wagon, taking a boy to help him in and out. He walked with one crutch with assistance also on one side, he was able to fish, and had been on a successful fishing trip during the summer.

"A girl of eighteen, affected in 1914, in January could barely walk alone. In July she walked with a slight limp. Eight

important muscles had recovered under persistent exercise, and the improvement began a few days after starting on exercises, previous to which the patient's progress had been stationary."

The table given in the section on symptoms is of value in prognosis as there is given in it the proportion of partial to total paralysis. Other facts have been mentioned in the same section suggesting the frequency of total paralysis below the

FIG. 8.—Mode of progression in a child with contraction deformity of hip and knees, untreated. The body is lifted along by the hands.

knee (82 per cent. of all cases) and the frequency of severe paralysis in the shoulder.

In muscles which remain totally paralyzed to attempts at voluntary contraction at the end of three months the outlook for the recovery of any marked degree of function is not good but neither is the situation hopeless.

The modern prognosis, therefore, is wholly different from the old prognosis. In 1886, Gibney,[1] already an authority in orthopedic surgery, wrote: "He must be a bold optimist in therapeutics who can see in any drug, in any agent, in any appliance

[1] V. P. Gibney: "New York Med. Jour.," Apr. 3, 1886.

a power which will restore the muscles whose nerve supply comes from these once living ganglion cells. . . . In other words all our skill is directed toward limiting the paralysis and correcting or preventing the deformity which so frequently follows." Today one would say that the modern early care perhaps limited the paralysis by omitting meddlesome therapeutics, that we had learned that most deformities could be prevented, that we recognized the fact that the great majority of muscles were weakened rather than paralyzed and that we had learned that impulses might often be sent from the brain

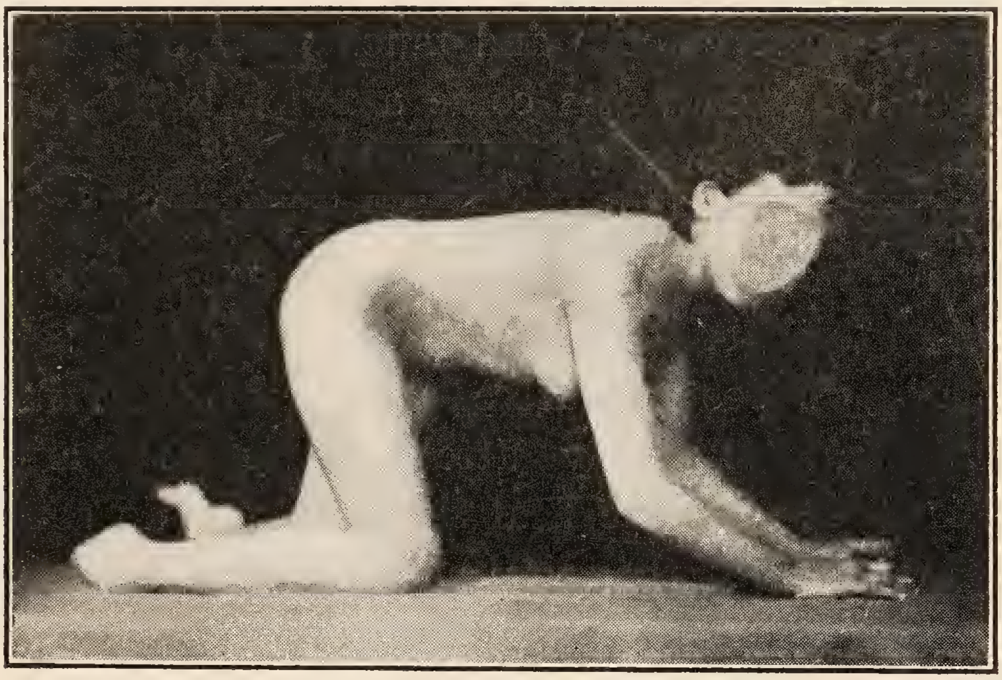

FIG. 9.—Quadruped progression in a severely paralyzed child. Never treated.

around the destroyed centers by new paths to the muscle and that this was best accomplished by muscle training, and finally that skillful muscle training and the proper care of weakened muscles were of the greatest importance in influencing the ultimate degree of function. We should no longer be content to put on a brace and let the child get about as best he can. This, from today's point of view, would be the crudest of treatment.

Two classes of cases are probably not much affected by treatment: first, those where the affection is so severe that it has left behind an extensive flaccid paralysis; and second, those which are so slight that they are going to recover anyway. In the opinion of the writer in practically all other early cases the matter of precise, effective and intelligent treatment

has great effect upon the prognosis as to ultimate function—and it must be further remembered that all cases must undergo a period where they must either have non-operative treatment or no treatment at all. Because all experienced men all agree that operative treatment is not to be undertaken till two years after the onset and this leaves a space of two valuable years when the case may be treated in the best way or loosely treated or neglected.

Prognosis after Operation.—It would be unfair to judge the post-operative results to be obtained to-day by the literature of a few years ago. Modern operating has become much more simple, much more definite and much more effective. With this increased efficiency has come a much larger number of operations and the prospect of improving function in cases formerly irremediable. The question of acetonuria in operating on children with infantile paralysis must not be forgotten for in the writer's experience this class of children seem more likely to acquire post-operative acetonuria than in others. The operations are rarely attended by any appreciable risk to life and the tissue heal as readily as do sound ones. When fractures occur; they heal normally.

CHAPTER II

TREATMENT

THE ACUTE PHASE—SERUM AND DRUGS—REST—QUARANTINE —PREVENTION OF DEFORMITY—SUMMARY OF TREATMENT

The treatment may be divided, for purposes of discussion, into three phases.

I. *The acute phase*—from the onset to the disappearance of the tenderness.

II. *The convalescent phase*—beginning at the end of the acute phase and continuing so long as spontaneous improvement (about two years) is marked.

III. *The chronic phase*—when the affection has become more stationary and deformities if present have become established.

These phases or stages appear to be as well marked as are those of most affections thus subdivided, but at times they run into each other and are often imperfectly separated. They are used in this instance merely to simplify description by subdividing the subject.

Plan of Treatment.—A general plan of treatment may be formulated which may make clearer the detailed description which comes later. In the *acute phase* our efforts are confined chiefly to limiting the destructive process. In the *convalescent phase* which will carry us practically two years from the onset there is no question of any operation (except minor tenotomies) and our efforts are concerned with the restoration of muscular power and the prevention of deformity. This is the time in the writer's experience where the greatest gain is to be made in the matter of ultimate function and, because all cases will in any event be non-operative during this period, much stress must be laid on it for this reason. The considerations governing its management are as follows: Many muscles are weakened and some are wholly paralyzed because of injury to certain nerve centers. Weakened muscles may be strength-

ened by muscular exercise and in addition to this, impulses sent from the brain to the muscle may be trained to find new paths. This is because the communications between the nerve centers and the connections between the nerve centers and muscles are very extensive and intricate and because most often not all the centers controlling one muscle are wiped out. As a result of this, muscle training in this period is physiologically sound and practically of great value and reinforces and establishes the normal spontaneous improvement. For this reason it has been considered in detail. Moreover, fatigue must be avoided and normal ambulatory conditions restored so far as possible by apparatus.

At the end of about two years the *chronic period* may be assumed to have begun and here the treatment is more largely operative although the conditions of the convalescent period still hold to a less extent.

THE ACUTE PHASE

This phase may be regarded as beginning with the beginning of the onset and lasting until the tenderness of the affected limbs has practically disappeared. In 604 cases in the Massachusetts series analyzed by Lovett and Richardson the time of disappearance of pain and tenderness was as follows:

	Cases	Per Cent.
One day or less	11	1.8
Two days	22	3.6
Three days	29	4.8
Four days	15	2.5
Five days	14	2.3
Six days	3	0.5
A few days	28	4.6
One week	59	9.7
One to two weeks	91	15.1
Two to three weeks	46	7.6
Three to four weeks	33	5.4
Four to five weeks	1	0.2
Six to seven weeks	1	0.2
One to two months	28	4.6
Two to three months	5	0.8
Several months	3	0.5
Until death	39	6.5
Present when report was made	175	29.0

We have no knowledge at present of any drug or serum or means of treatment which will protect from infection, abort the attack, or prevent the paralysis. Even if we make the diagnosis in the pre-paralytic stage it must be remembered that practically we are no better off than without it, so far as preventing the paralysis is concerned. Netter[1] of Paris has advocated the injection into the spinal canal of blood serum from recovered persons and reports thirty-two cases in which he believes the paralysis has been modified by the treatment, but the matter is still in the purely experimental stage and has not yet received general confirmation although reported by one other set of observers.[2]

Since it was shown by Cushing and Crowe that *hexamethylenamine* (urotropin) is in part eliminated into the intradural space it has seemed possible that it might be of value in early infantile paralysis and it has been extensively used in the treatment of the acute stage of the disease and in prophylaxis. The experimental evidence for its use is as follows:[3] "when a large dose of the drug is administered by mouth, its presence can be detected by chemical tests in the cerebro-spinal fluid soon afterwards. We have ascertained that when the virus of poliomyelitis is injected intracerebrally in monkeys in which the hexamethylenamine is already present in the fluid, and the drug is then administered by mouth daily thereafter, that in a proportion of animals so treated, but not in all, first, the incubation period of the disease is prolonged (from six to eight days to twenty-four days) and next the onset of the paralysis is entirely prevented. When the drug is administered by mouth and the immune monkey serum by injection into the subdural space, the paralysis can also be prevented and possibly with greater certainty." There is no experimental evidence that the drug is of any value when infection has occurred.

On this evidence the use of hexamethylenamine seems warranted and legitimate as a prophylactic when such is desirable. In the early stages of the disease it is extensively

[1] Netter: "Bull de l'Acad de Med.," Oct. 12, 1915.
[2] Alfaro and Hitce: "Summa Medica, Buenos Aires," Aug. 5, 1915.
[3] Flexner and Clark: "Jour. A. M. A.," Feb. 25, 1911, p. 585.

used especially in the pre-paralytic stage and at times it appears to be useful but there is no evidence in any individual case that can be relied on to prove that it has been of any value. Still in the absence of any remedy of proved value its use seems legitimate in the early stages, on general grounds, on experimental evidence, and because used with care it is harmless.

Rest in bed at this stage is strictly to be enforced in all cases.[1] In the moderate and severe grades of the affection the patients are too ill to be elsewhere than in bed, but in the slighter cases it is well to remember that the pathological condition is a hemorrhagic myelitis and that function of the affected members means function of their motor nerve cells and that such function is probably harmful on general principles. In all grades of the affection it is obviously indicated to secure the maximum degree of rest and quiet even where it is not necessitated by general prostration, pain and tenderness.

A German writer[2] has advocated the application of a jacket of plaster of Paris to ensure absolute quiet to the vertebral column but this seems hardly necessary and is not often done. During this stage joints will not become ankylosed, muscles will not become hopelessly wasted, the circulation of the affected members will not become seriously upset if the patient is let alone, whereas if the patient is not let alone and is massaged, manipulated, treated with electricity, etc., during this stage, there is a strong possibility that the recovery may be less extensive than it would otherwise have been. That massage during convalescence is harmful so long as the patient is tender has been shown in two of the writer's patients. In one, a boy of seven, the tenderness was slight at the end of ten weeks, and gentle massage of five minutes was prescribed with a view of hastening its disappearance. In a week this boy was so tender that he could not bear the weight of the bedclothes, and was put in plaster of Paris for a week, during which week the tenderness disappeared. A girl of fifteen in the fourth week of her disease was massaged twice daily in a general hospital, being given heavy massage by a person without especial train-

[1] Robert Jones: "British M. J.," May 30, 1914.
[2] Hohmann: "Munch. Med. Wchsft.," 1909, No. 49.

ing. Her suffering became so great that she was placed in a private hospital, where the tenderness persisted to a marked degree for two months more.

There is absolutely no evidence to show that the use of electricity at this stage is of any benefit or has any local effect either upon the organism or the affected cord. This point is emphasized because parents, relatives and inexperienced practitioners have heard so much of rapid recoveries under massage, electricity and the like that such measures are often used too early, to the detriment of the patient. The fact is that the amount of early paralysis is dependent on the amount of tissue really involved during the acute attack, that no two cases are alike, and that much of the early paralysis is due to obstruction of the terminal spinal arteries and anemia of the centers, which speedily is recovered from. It is our business to see that during the stage now under discussion conditions are made as favorable as possible for the recovery of the spinal centers, and this recovery is obviously to be expedited by physiological rest to the affected centers.

Tenderness, which so commonly exists, is to be accepted as evidence of congestion and irritation of the cord, and consequently of a process still active. In cases where the tenderness lasts excessively long there seems no need of insisting on recumbency until it disappears, but when it has become distinctly less, the patient may be allowed to sit up, if this can be done without discomfort. At this time limbs may be passively moved to relieve joint stiffness, and parts of the body not tender may be gently rubbed. There is no evidence that strychnine, ergot, etc., are of any use at this stage.

At this period a warm bath is generally of benefit because the buoyancy of the water diminishes the weight of the limbs and permits motion which is not possible out of water because the limbs are thus supported. The addition to the bath of sea-salt of course increases the specific gravity of the water. Immersion in a bath is not desirable during the first two or three weeks of the paralysis but may be used before tenderness has wholly gone, the patient being lifted into the bath on a sheet.

A matter often lost sight of is that infantile paralysis is an infectious disease and that long-continued mild sepsis, loss of appetite and flesh may persist and should be borne in mind. In certain cases it may be months before the general condition becomes normal the general sequelæ being much the same as they might be after one of the acute exanthemata.

In the matter of quarantine it is generally assumed that the affection is transmissible,[1] that the virus probably enters by the respiratory tract and is apparently excreted in the secretions of the throat and nose. With regard to the length of time that the disease continues to be transmissible we have no exact information whatever, and any period set is largely guesswork. The rules regarding quarantine of two states are given as examples of the present point of view of representative boards of health in the matter.

Michigan.—1. Cases must be reported to local board of health.

2. Conspicuous placard on the house.

3. Quarantine of household four weeks minimum. Head of family and other adults may be released from quarantine after antiseptic bath and in disinfected clothing.

4. Complete disinfection of rooms and clothing after death or recovery of patient.

Minnesota.—Immediate notification by the regular reporting post card or special blank provided shall be made by the attending physician (or other person as specified) to the local health officer in cities and villages and to the chairman of the board of supervisors in townships of each case or suspected case of anterior poliomyelitis.

The patient shall be isolated for at least two weeks after the first symptoms appear. The patient's room shall be carefully screened throughout the course of the disease and during the convalescence if any flies or insects are about.

Nose, throat, and mouth discharges must be received on cloths and burned at once. Bowel and bladder discharges must be disinfected before being deposited in a sewer or cesspool. Where no sewer or cesspool exists, bowel and bladder discharges shall be disinfected and afterward buried in such a manner as to prevent the access of flies or insects to them. All articles exposed to possible infection from the aforesaid discharges must be cleansed and disinfected according to the directions of the State board of health.

In case of death the funeral shall be strictly private. Children in the

[1] Flexner: "Jour. A. M. A.," Oct. 12, 1912.

house, and persons associated with the patient, shall be kept under observation for two weeks after last exposure. During this period the children shall not attend any public, private, parochial, church, or Sunday school, or any public or private gathering whatever. Residence, boarding or lodging in the house during the isolation of the case shall constitute exposure.

The prevention of contractions and early deformity is of great importance at this stage of the affection for such contrac-

Fig. 10.—Severe talipes equinus of right foot.

Fig. 11.—Dropped foot from complete paralysis of the foot in that position simulating equinus but without hollowing of the sole.

tions may occur early and are on the whole evidences of neglect and lack of proper surgical care. This is not the case in regard to scoliosis.

These contraction deformities occur earlier than generally supposed and marked equinus deformity has been observed at the end of three weeks and noticeable scoliosis in a recumbent patient in four weeks. One hundred and fifty cases of the 1914 epidemic were seen in Vermont at from two to six

months after the onset. There were only sixteen cases of equinus deformity, this small number undoubtedly being due to the care taken by the doctors in the acute stage. There were nine cases of flexion of the knees and seven of flexion of one or both hips. In one case both hips were flexed and one knee contracted to a right angle and the other to 45 degrees. There were sixteen cases of scoliosis and four of hyperextension of the knee. These figures show how early in the affection serious deformity may arise.

It may thus be seen that many cases reach the convalescent stage with shortened muscles due to neglect while they have been lying in bed. If the feet are not supported they are likely to drop into a position of plantar flexion, a position aggravated by the weight of the bedclothes, and when the patient is ready to be stood on his feet he may be found to have acquired an adaptive shortening of the gastrocnemius muscle—in other words, a mild talipes equinus. If this exists he cannot stand or walk properly with or without braces until it has been removed.

To prevent this the feet should be supported at right angles to the legs from the outset by plaster-of-Paris splints, right-angled tin splints, leather splints or anything of the kind, which can be worn most of the time, and for the rest of the day the patient's feet may be supported at right angles to the legs by means of a soap box, resting at the foot of the bed against the foot board, covered with a blanket and placed under the bed-clothes for the feet to rest on and thus be held at a right angel to the legs.

Lateral curvature of the spine sometimes begins while the patient is lying on his back but in a case whose back muscles are as severely affected as this, it seems likely that little would be gained by treatment begun during the recumbent period. There is therefore no especial treatment to be advised at this stage for the scoliosis, beyond the unnecessary assumption of attitudes aggravating the back deformity.

In occasional cases in this tender phase it is not wise to cause too much discomfort to prevent contraction and sometimes it is wiser, to cease aggravating the patient by painful attempts of

this sort, to allow the tenderness to disappear and then to remove the contractions by stretching as will be mentioned later (page 75).

In a case of this sort of the writer's in a girl of fifteen, tenderness has been greatly prolonged by heavy massage given early. When the patient came to the writer's care at the end of six weeks she lay with knees flexed and toes pointed and any other position caused great pain. Weeks passed with no great change in the tenderness and caliper splits were applied to the legs with a view of straightening the knees, but the pain was intolerable, the patient's general condition suffered, and the contraction became worse. Finally, all halfway attempts at correction were abandoned and the patient was let alone until tenderness had disappeared and the condition had quieted down which was four months after the onset. Then plasters were applied, cut and wedged as will be described and the legs straightened in three weeks without much discomfort. This case has been given in detail because it is a type of case occasionally seen where deformities must be allowed to occur in spite of careful treatment.

SUMMARY OF THE TREATMENT OF THE ACUTE PHASE

Rest until the tenderness has disappeared, absence of meddlesome therapeutics either medicinal or physical, the use of warm baths in the later part of this period. The prevention of contractions.

CHAPTER III

TREATMENT

THE CONVALESCENT PHASE—AMBULATORY TREATMENT—BRACES—BALANCE—PREVENTION OF PERMANENT DEFORMITY—STAGES AND VARIETIES OF DEFORMITY—DISLOCATIONS—RESTORATION OF NERVE AND MUSCLE POWER—MASSAGE—HEAT—ELECTRICITY—MUSCLE TRAINING

THE CONVALESCENT PHASE

With the disappearance of the tenderness the acute stage of the process in the cord may be assumed to be at an end and the time to be at hand when one may make an estimate of the damage done and plan the campaign of treatment. This stage has been in this book arbitrarily assumed as beginning with the cessation of tenderness and ending when spontaneous improvement has largely ceased, *i.e.*, when the case has become in large measure stationary. That the cessation of spontaneous improvement occurs far later than formerly supposed has already been mentioned and the end of this phase is difficult to fix although it may be arbitrarily set at about two years after the onset because during this time all are agreed that major operative procedures are not to be undertaken.

So far as treatment is concerned the situation is as follows: A hemorrhagic myelitis accompanying a general infection has destroyed or impaired or temporarily inhibited the function of certain nerve centers, the muscles controlled by these centers have been inactive and have wasted, the circulation has become sluggish, and the general resistance of the patient is below par. But the time has come to begin the work of restoring the maximum function to affected muscles, and one must carefully consider what means will most rapidly bring this about.

AMBULATORY TREATMENT

It is on the whole desirable for the patient to get into the upright position early in the convalescent phase. The reasons

for this are: first, that the prolongation of the recumbent period is unnatural and undesirable on account of its effect on the circulation because the circulation is stimulated and regulated by the normal upright attitude and undesirably affected by prolonged recumbency; second, because the sitting and later standing attitude is a stimulus to the muscles themselves and to the nerve centers controlling them to attempt to balance the body and thus incites instinctive action on the part of a large number of muscles, exercising in this way muscles which could not otherwise be reached; third, because the nervous system of children of the age generally attacked is as a rule unfavorably affected by prolonged inaction and recumbency; and fourth, because outdoor air and diversion are on general grounds desirable.

There is, however, the danger of overusing the muscles by this proceeding and some writers[1] are in favor of prolonged disuse of affected muscles. But the old practice is too common of allowing patients to sit or lie around for months or years with no attempt to walk until many of them have developed serious flexion deformities. On the whole, therefore, it is the belief of the author that the upright position and very restricted ambulatory activity should be undertaken within two or three months of the onset, except in unusual cases. Fatigue, as will be mentioned, is carefully to be guarded against, especially in walking too early with muscles still weakened.

Sitting in many cases is at first impossible on account of weakness of the spine and abdomen but in such cases the patient may be first propped up in a chair with pillows until he is able to sit alone. This must be determined by the patient's resistance. All cases should be carefully watched at this stage as to the presence or development of lateral curvature of the spine a condition too frequently overlooked. If the spine tends to curve in the sitting position the patient should be made to sit in a way to counteract the curve.

Abdominal paralysis or weakness frequently occurs and is not infrequently overlooked and demands attention. The child is unable to rise from the lying to the sitting position unaided

[1] Judson: "Denver Med. Times and Utah Med. Jour.," Oct. 1, 1907.

FIG. 12.—Extensive paralysis of two years' duration showing abdominal paralysis, scoliosis, talipes equinus on right. Paralysis of both legs.

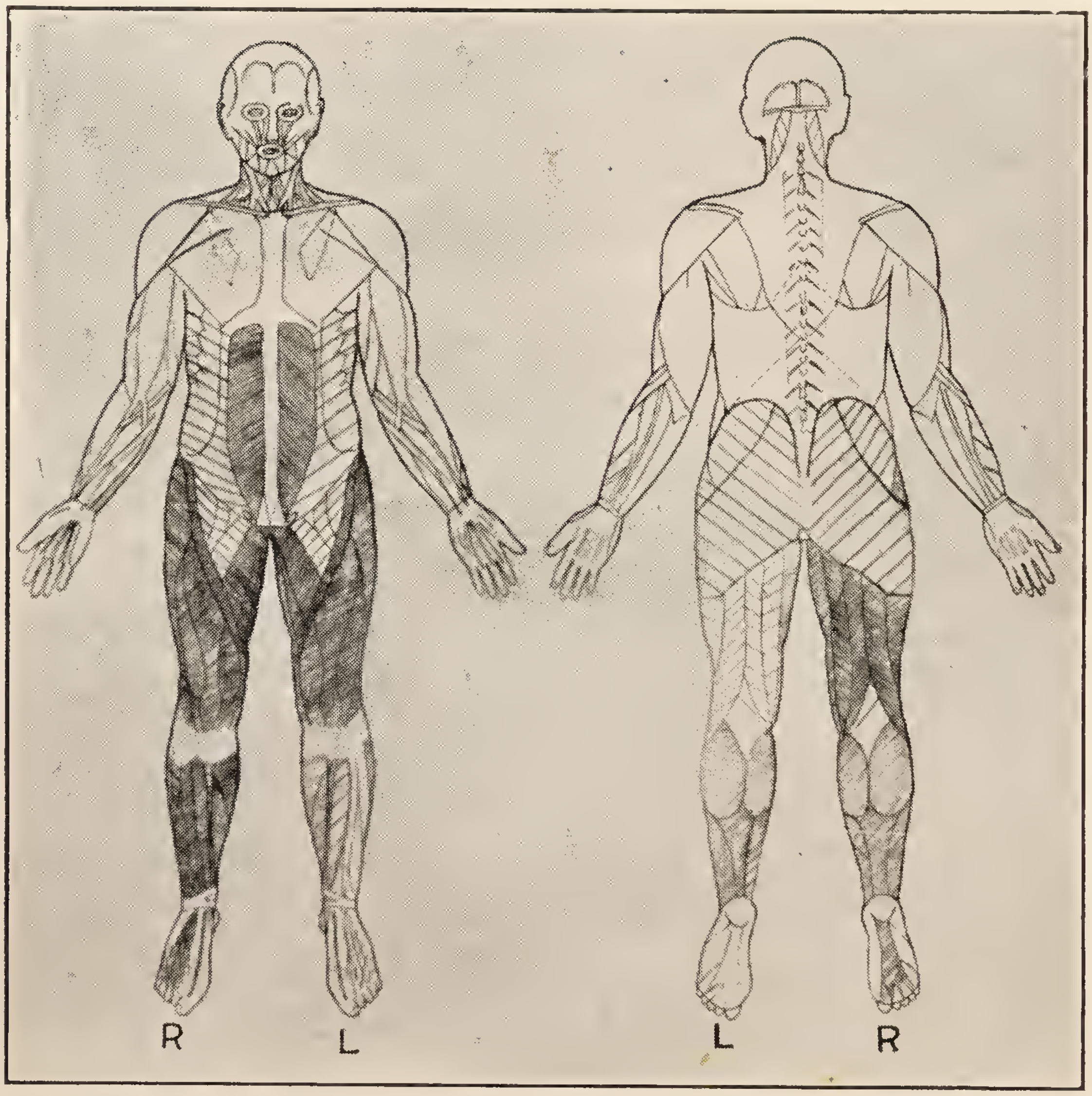

FIG. 13.—Muscle chart of the patient shown in Fig. 14. The normal muscles are not shaded; the partly paralyzed muscles are shaded with coarse lines. The wholly paralyzed muscles are closely shaded.

and in sitting the abdomen is prominent and the child sits with the spine flexed. If this is allowed to go uncorrected the lower edge of the thorax begins to flare out where it rests on the fluid abdominal contents and permanent bony deformity may occur. One-sided paralysis of the abdomen may rarely be found. In all cases of abdominal weakness or paralysis an abdominal support should be furnished by means of an accurately fitted cloth corset. In many cases recovery will occur under these

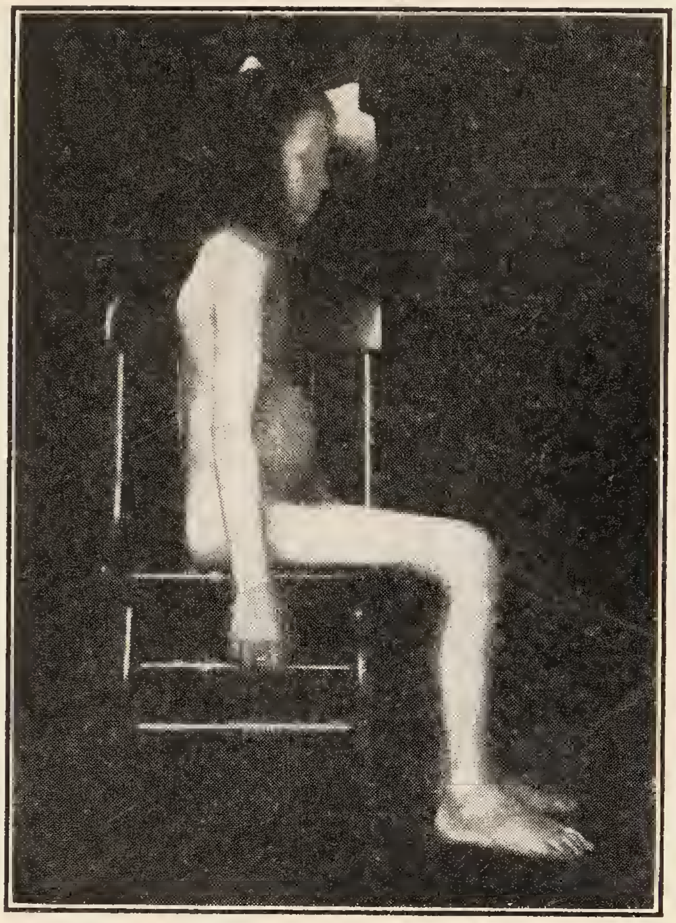

Fig. 14.—Abdominal paralysis combined with extensive leg paralysis. The affected muscles are shown on the chart in Fig. 13.

conditions which probably would not have occurred had the muscles remained unsupported and continually stretched.

WALKING WITHOUT BRACES

From the time when the patient is able to sit alone he may or may not be able to walk without apparatus. Even if he can, it must be remembered that affected muscles have in the early months after the attack, greatly impaired power and can be easily fatigued and that such fatigue is detrimental to their welfare. It must be strongly urged when the power has returned rapidly and early walking is possible that great care

should be taken to guard against fatigue—walking at first being limited to only a few steps and for the first months in all cases being reduced to a very small amount. Fatigue may be noticed by a flagging in the walk or by a feeling of local or general tiredness.

BRACES FOR WALKING

In case the patient cannot stand or walk unaided, or stands or walks in a position of deformity as, *e.g.*, with a knee hyper-

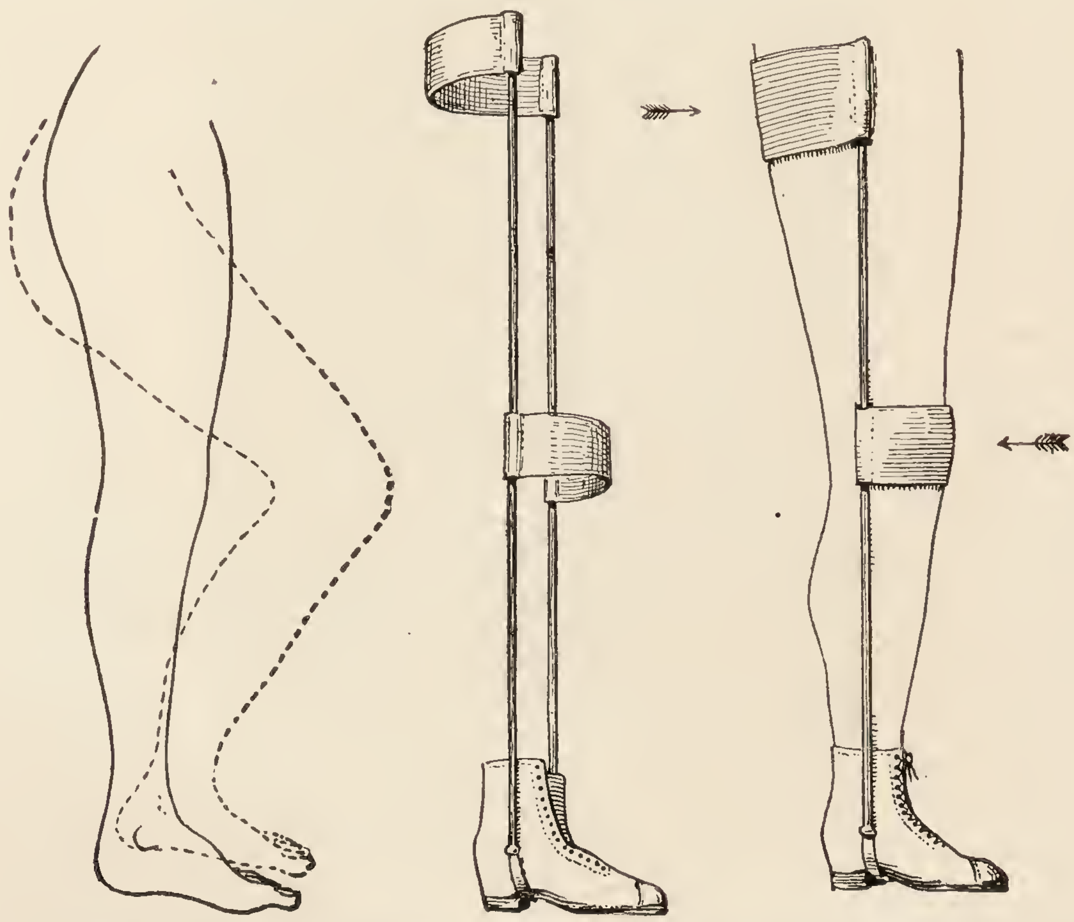

Fig. 15.—Mechanics of apparatus required to prevent knee from flexing in paralysis of the quadriceps muscle. (*Bradford and Lovett.*)

extended, the use of a brace becomes advisable, for the problem of getting the patient onto his feet is just as urgent as if he could walk unaided. A patient, however, may be extensively paralyzed in the leg and yet be able to get about without braces or assistance—and the use of a brace is not to be advised unless it has a definite requirement to meet. Paralysis of the leg below the knee for example, as has been mentioned, does not require the use of the brace, although apparatus sometimes diminishes the limp. If certain other muscles are affected, however, which have been mentioned in prognosis (page 22) a brace becomes essential for ambulatory activity. This point is emphasized

because so many children to their great detriment are allowed to lie or sit around for months or years after the attack with no attempt to encourage functional activity. This is most undesirable because it promotes muscular atrophy by disuse and favors deformities which are more likely to occur in a patient who always sits with the legs flexed and the feet hanging than in one going about with proper apparatus.

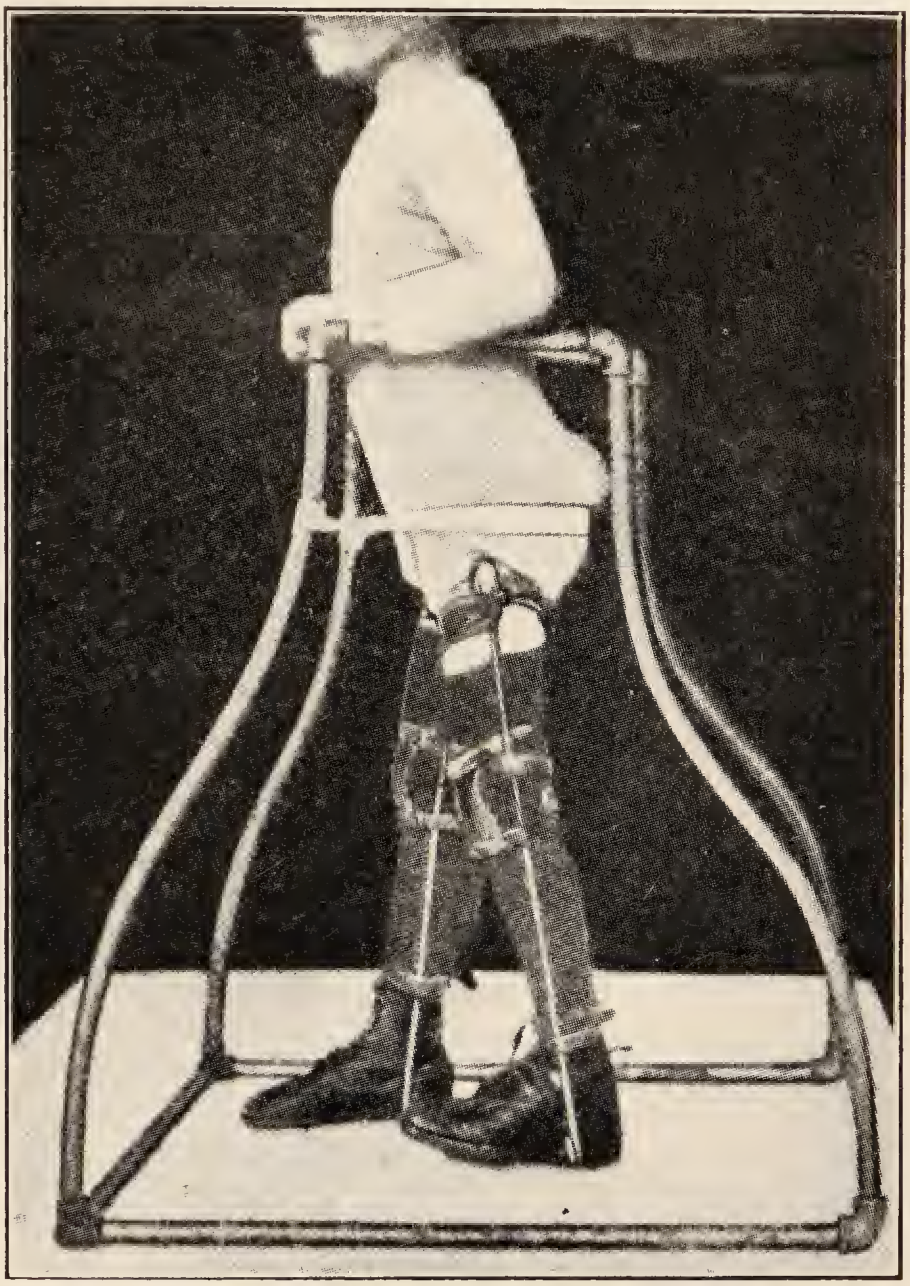

Fig. 16.—Paralyzed child strapped in a walking frame wearing splints to prevent forward dropping of the knee. (*Boston M. and S. Jour.*)

As the quadriceps extensor femoris is of all muscles in the body the one most frequently paralyzed (152 in 1,452 groups) the splint to supplement that is of great importance in this connection and of all the appliances to be used in infantile paralysis is the one most generally necessary at the outset.

The splint is a so-called "caliper" made of heavy iron

wire one-quarter inch or more in diameter. Two pieces of this run up on the outside and inside of the leg, respectively, and are joined together at the top just below the gluteal fold by a

FIG. 17.—Side view of "caliper" splint, with knee strap and checks in the heel to prevent the dropping of the heel or front of the foot as may be needed. (*Boston M. and S. Jour.*)

posterior iron band which is curved and padded. Below at the level of the sole of the boot these irons are turned at a right angle to fit into a tube in the heel of the boot, a fenestrated

leather knee cap passes over the front of the knee to keep it from flexing and a circular leather strap passes around the two irons below to keep them from spreading and slipping out of the tube in the boot.

This apparatus is not generally in the first instance jointed at the knee as it is lighter without being jointed.

Dropping of the toes is prevented when necessary by a flange which is fastened to the heel of the boot which strikes against the splint upright thus preventing the dropping of the foot but

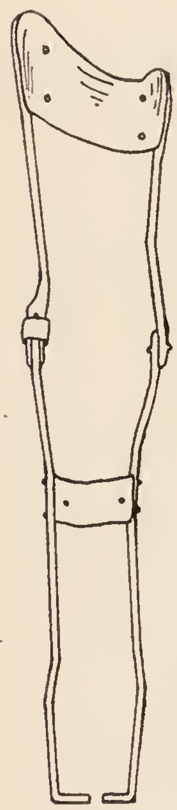

FIG. 18.—Jointed caliper splint.

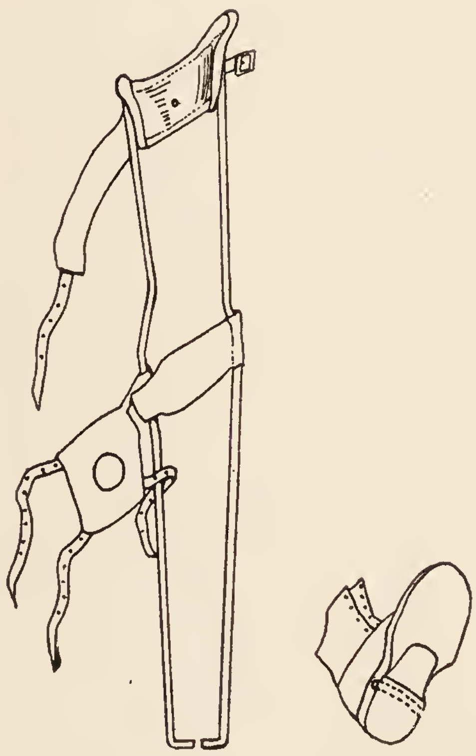

FIG. 19.—Thomas caliper splint.

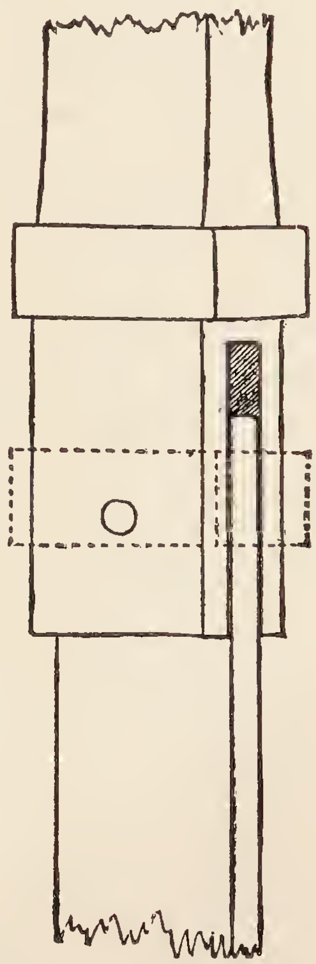

FIG. 20.—Drop catch for knee splint. (*Bradford and Lovett.*)

allowing dorsal flexion. With this appliance on, the patient may be placed on his feet and held under the arms, or an upright board may be set up and the patient strapped to that by straps passing under the arms, thus getting used to having his weight come on his feet.

With this appliance the patient's legs are converted into props for the trunk, but the trunk must be held erect on the legs by the glutei muscles before he can stand or walk unaided, or the deficiency of the glutei muscles must be supplied by

crutches which will hold the trunk erect on the legs, thus making the action of the glutei less necessary for maintaining the upright position. Of course, these remarks apply to the severer cases and in the milder cases, as in the affection of the quadriceps of one leg, the mere application of a caliper and splint is enough to enable the patient to walk without further assistance.

The caliper braces spoken of are later replaced by braces

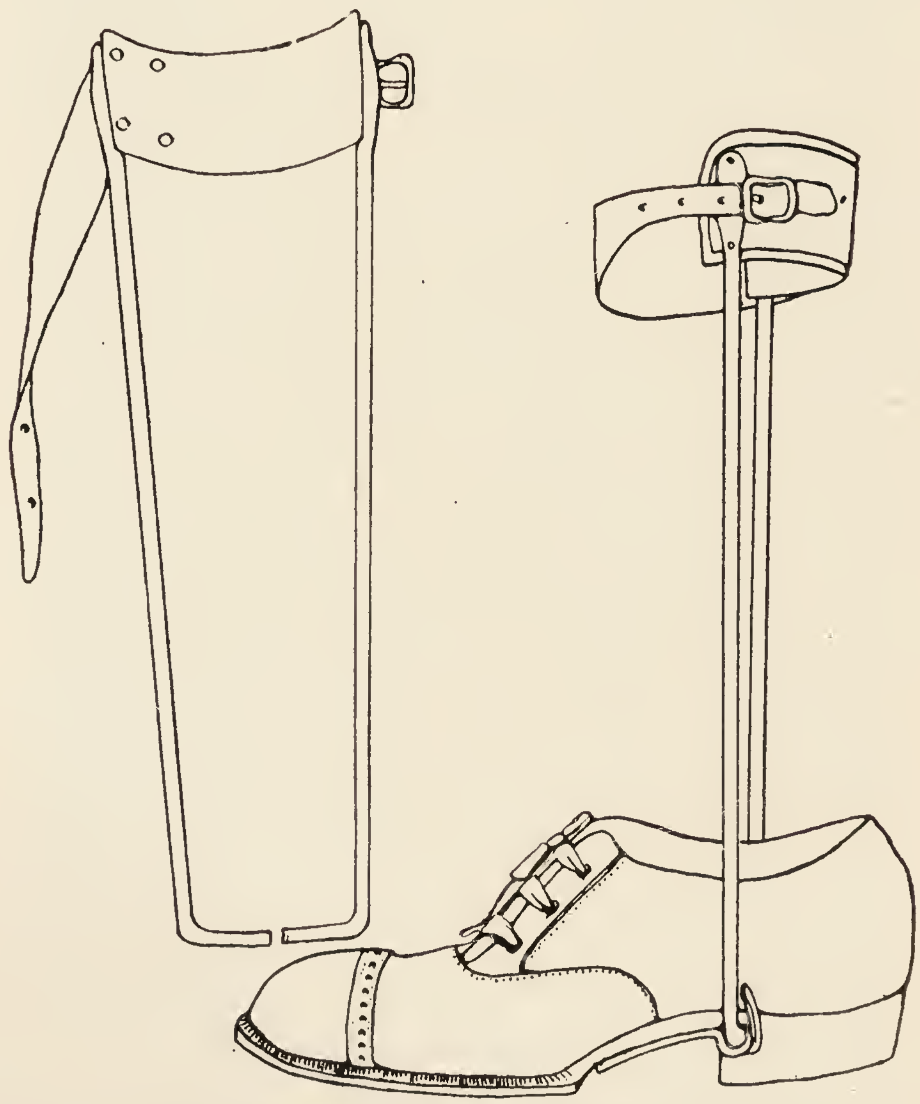

FIG. 21.—Detail of wire splint, showing adjustment to the shoe, with check to prevent toe-drop. (*Boston M. and S. Jour.*)

made of flat iron shaped to the leg and jointed at the knee. Such braces can (1) either be fastened to the boot by being attached by a plate to the under side of the sole, or (2) they may end in a plate going inside of the boot to which the foot may or may not need to be strapped, or (3) they may end just as the calipers do by being turned at a right angle to fit into a tube in front of the heel of the boot.

In cases of weakness of the *gastrocnemius* even of the slight-

est grade it is desirable to raise the heels of the shoes in order to prevent the weight of the body from coming upon and stretching the muscle in walking. The heels of the boots of young children should be half or three-fourths of an inch high

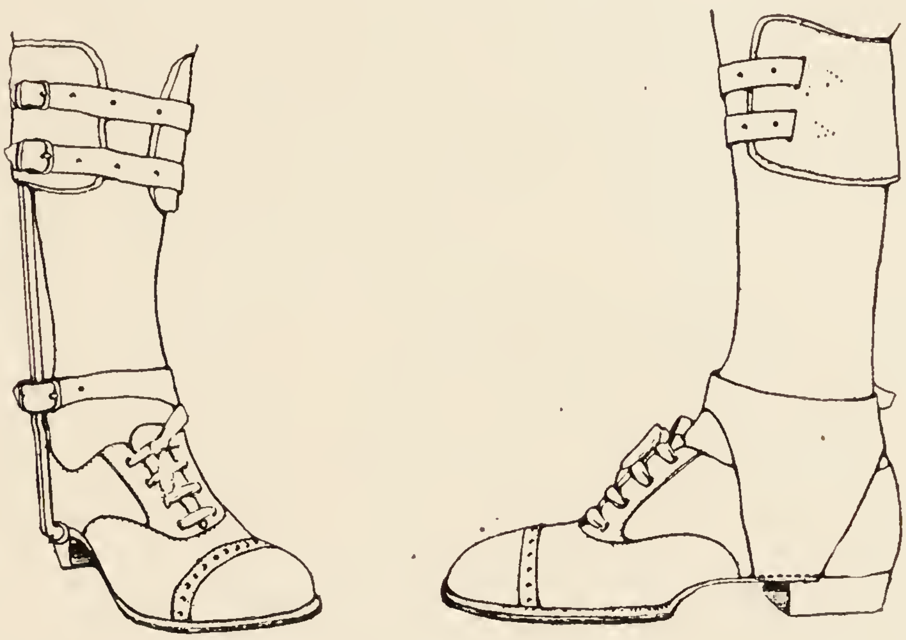

FIG. 22.—Apparatus with ankle strap to check paralytic valgus. If the upright is applied to the inside with the ankle strap applied to the outside a varus deformity is checked. (*Boston M. and S. Jour.*)

and of older children an inch to an inch and a half and the weight of the body should not be allowed at any time to come upon the foot without the boot, that is, barefoot walking even in undressing, sneakers, tennis shoes, etc., should be absolutely

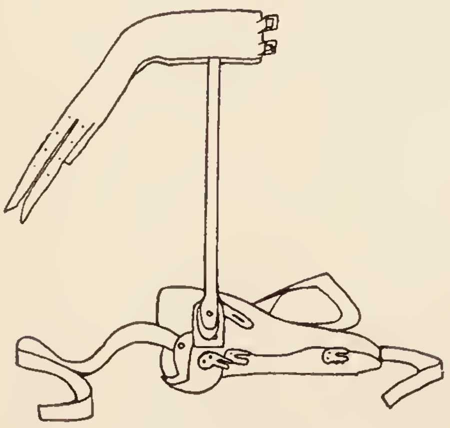

FIG. 23.—Taylor varus shoe.

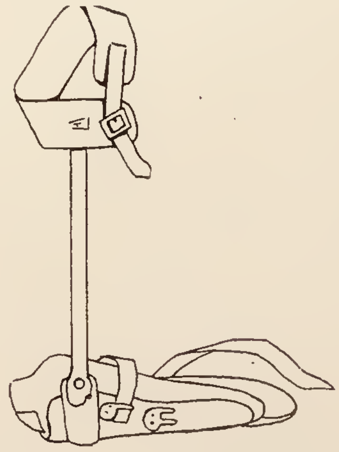

FIG. 24.—Valgus shoe.

forbidden. In this way apparently stretching of the muscle is prevented, its recovery or improvement favored, and permanent talipes calcaneus avoided in many cases.

If there is total paralysis below the knee the foot will drop and the gait be ungainly. This may be checked by a sole

plate attached to two uprights running two-thirds of the way to the knee and ending in a posterior calf band at this level (Fig. 75). Or a short caliper may be used ending below the knee. A stop catch at the ankle will prevent dropping of the foot beyond a right angle. In such cases of leg paralysis if the foot turns neither onto the inner nor the outer border a plate in the shoe or fastened to the bottom of the shoe will suffice. If it rolls onto either side, that is, into varus or valgus positions, a sole plate such as is used in the Taylor club-foot shoe or the reverse of this for valgus will be required.

Summary of Walking Apparatus.—The question of apparatus for the leg is rather simple. Apparatus is used to prevent persistent malposition or to make walking possible or to improve walking.

Generally the defect is that the patient cannot hold the knee straight and a splint to do this is desirable (the caliper leg splint). If the glutei are involved these braces may have to be fastened to a leather jacket by posterior straps to keep the trunk erect on the props.

The problem is made more difficult when the arms are involved because the patient cannot, in that event, use crutches easily. But an arm badly paralyzed enough not to be able to hold a crutch is fortunately the exception and where the use of crutches was necessary for walking no case in the writer's experience has been kept from walking by the paralysis of the arm because it has been possible in most instances to teach the patient to hold a crutch in some form or other.

That apparatus should be light is essential. It is a great burden to weight a weak leg with several pounds of metal and a tax on muscles as a rule unable to bear an extra tax. It is also necessary that apparatus should fit accurately and be mechanically sound. In no department of orthopedic surgery is the careful attention to the fit of apparatus so desirable as in infantile paralysis.

Objections to the use of apparatus are evident, because it cannot be otherwise than undesirable to put onto a weakened limb an apparatus which means extra weight and muscular constriction by the bands or lacings required to hold it in

place. It must be remembered that such apparatus is put on only to make walking possible, or to prevent deformity and that it should *not* be worn when not required for walking, that is, not continuously except in those cases of long standing where further muscular gain is hopeless.

But granted that apparatus is undesirable the conditions which it is put on to prevent are still more undesirable. These are (1) inability to walk, and (2) the acquirement of malposition and permanent deformity.

BALANCE

But between the time when the extensively paralyzed patient can stand supported as described and the time when he can stand alone or walk with or without crutches, there is one absolute necessity, namely he must learn to balance. The sense of equilibrium is often greatly impaired by the prolonged recumbency and when the patient thus severely affected is placed on his feet he is quite unable to keep any balance either with or without crutches.

This is not necessarily a matter of muscular paralysis for in a week perhaps, or in two or three, with no especial increase in muscular power he may be able to stand on crutches without assistance and learn to walk a little. Thus the sense of balance, that is the sense of equilibrium must be reckoned with by itself as independent of the paralysis and as perhaps one of the first needs of the case beginning on ambulatory treatment.

This was strikingly shown in a case of the writer where a woman of twenty-eight had never walked without crutches since an attack of paralysis of both legs at the age of three. With crutches she could get about but when the legs were converted into props by means of braces she had no power of remaining erect without crutches. Yet in two or three weeks she could stand alone and walk a little.

To repeat, the sense of balance must be reckoned with in all severe cases and must be trained by repeated drills in standing with crutches and support of the nurse's hands by holding onto the furniture, etc., and it must be remembered that

often the primary difficulty experienced in standing erect in proper splints may be due not wholly to the paralysis but also to the loss of equilibrium.

Learning to Walk.—It is thus evident that walking and even standing are impossible until the sense of equilibrium has returned. From that time all attempts at starting on walking should be made with such manual assistance as may be necessary.

When standing with braces and crutches but unsupported by outside assistance is possible the patient should next be encouraged to advance the crutches one at a time and drag the

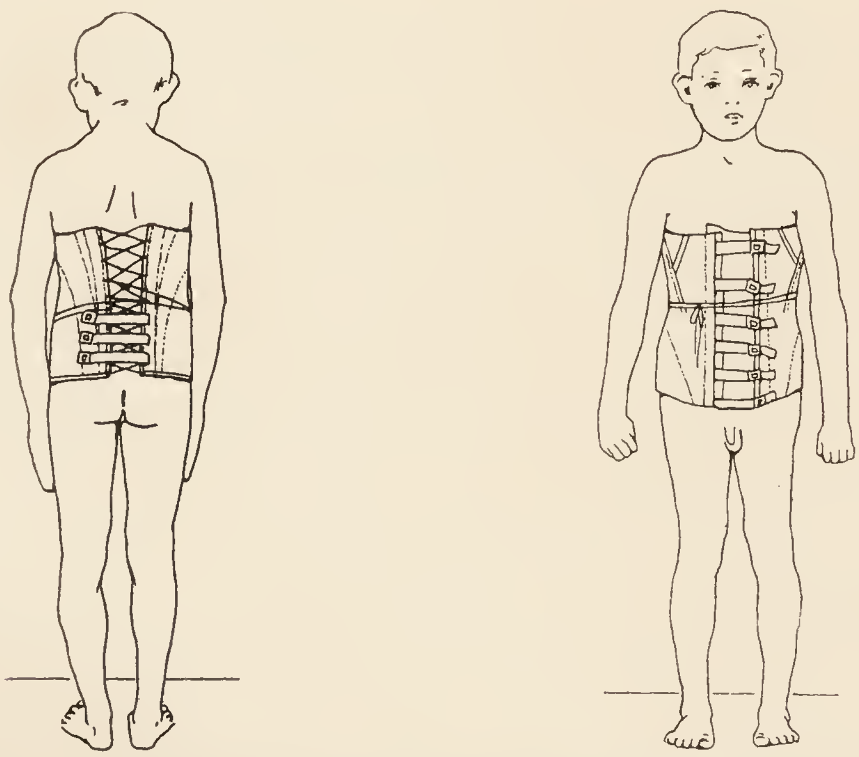

FIG. 25.—Corset for use in paralysis of back or abdomen.

feet forward to them and then to advance the crutches again and again drag forward the feet. A tripod is thus formed the two forward supports being the crutches and the legs forming the posterior support.

One essential fact to be remembered in this connection is that in severe cases the trunk can flex on the legs to any extent but that hyperextension is checked at the hips by the **Y** ligaments. So that in standing and walking, flexion at the hips must be guarded against but hyperextension at the hips is not a danger. Hence the patient with no gluteal power can walk by dragging the legs along behind the body, the center of gravity thus falling well behind the hips whose hyperextension is checked by the **Y**

ligaments. This is not the case when there is flexion deformity of the thighs on the trunk due to contraction of the tensor fascia lata as in these cases the center of gravity cannot be brought behind the hip-joints and the gluteal paralysis becomes then an obstacle to walking and standing. Patients with very severe paralysis may never learn to walk in any other way than this tripod progression, advancing the crutches and hitching along the legs together.

To walk one step at a time implies some degree of muscular power in the muscles controlling the hips and in the drill for walking a knowledge of the affected muscles must be accurately obtained and the line of least resistance followed.

It is obviously better that patients should if possible stand erect and walk with one leg at a time instead of dragging both legs together along behind them with crutches advanced.

In cases of extensive paralysis of the back and abdomen especially if associated as it often is, with involvement of the gluteal muscles, a leather jacket is necessary to support the back and abdomen and, if gluteal paralysis be also present, straps may pass from the back of each splint to the back of the jacket, which straps in a way supplement the need of gluteals by keeping the trunk from flexing on the legs. In short the patient from the axillæ down is encased in a stiff apparatus which prevents flexion of the legs on the trunk and enables walking but of course such straps must be loosened before setting down.

General Considerations as to Treatment at This Stage.—The considerations so far presented have dealt with the means and desirability of promoting the upright position and ambulatory activity at this stage of the affection. A question of equal or even greater importance considers what therapeutic measures are best calculated to promote the welfare of affected muscles and to bring them to their highest efficiency, a question of the widest application and of the utmost importance. It has been stated that the observations on 300 cases examined in Vermont have shown that in all cases, old and recent, infantile paralysis has been found in most muscle groups not to be a paralysis in the sense of a complete loss of power but a weaken-

ing of these muscles. By manual examination partial paralysis bore to total paralysis the proportion of 2.5 to 1 and by the muscle test 9 to 1.

Our therapeutic problem therefore requires the closest possible study of such muscles and of the remedial measures by which their individual power may be increased.

Fig. 26.—Talipes equinus left foot—walking position.

Moreover as in the earlier stage just discussed deformity must still be guarded against for its occurrence greatly complicates treatment and renders it far more difficult.

We have, therefore, before us at this stage two primary requirements: (*a*) *the prevention of permanent deformity* (the prevention of early deformity in the acute phase having been discussed under that heading; and (*b*) *the restoration of all possible muscular power* to affected muscles.

(*a*) PREVENTION OF PERMANENT DEFORMITY

The prevention of permanent deformity at this stage will first be discussed.

The prevention of deformity is too little insisted on, and it is probable that the occurrence of serious fixed deformity is, except in paralysis of the spine and shoulder, nearly always unnecessary. A competent orthopedic surgeon would, except in a very unusual case, be ashamed of the occurrence of serious fixed deformity of the foot in any case under his control from the early stage of the affection, yet many cases of infantile paralysis sooner or later acquire some deformity. In any discussion of paralytic deformity it is a very serious part of our business to educate the general practitioner, the surgeon and the neurologist to the point of recognizing such deformity as in general an evidence of neglect.

As paralytic deformity arises from various causes, it occurs in various forms. Intelligent treatment, operative or mechanical, must start with an analysis of the cause and character of the deformity.

FIG. 27.—Severe talipes varus of right foot.

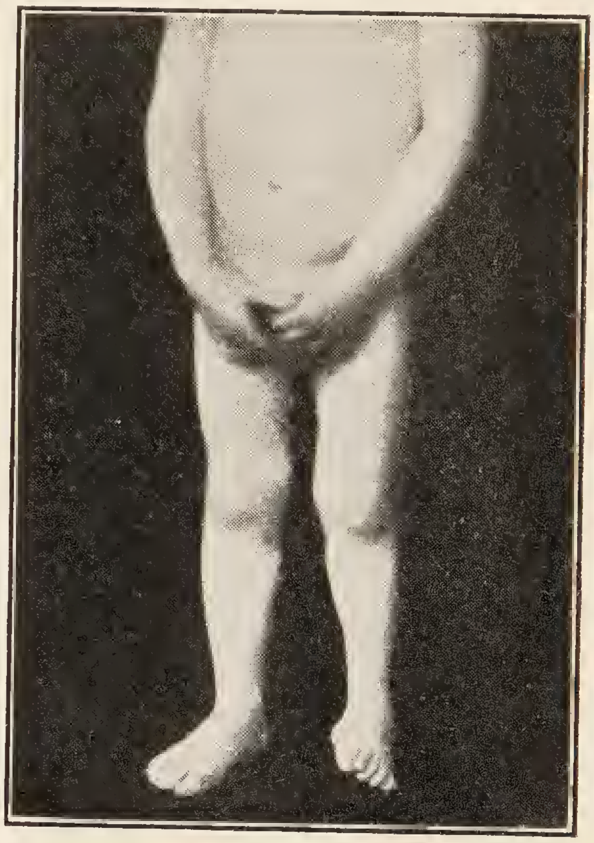

FIG. 28.—Talipes varus, left foot, moderate in degree.

DEFORMITY AND ITS STAGES

There are three stages in the development of deformity in infantile paralysis which are as follows:

1. **Constant malposition,** in which the limb can still be replaced in the normal position without the use of force.

2. **Adaptive changes in the soft parts,** consisting of lengthening on the stretched side of the joint, and shortening on the other, which occur in most cases which are subject to prolonged malposition. In some cases, however, this does not occur and the joint remains flail.

3. **Permanent bony deformity** must occur if the malposition remains permanent during the years of growth. Bone is an adaptive structure, and notably so while developing, because in its growth it follows the line of least resistance. The bones of the foot, for instance, develop normally only when the foot

is normally used and a persistent valgus, *e.g.*, is followed by a distortion of the individual bones of the foot to the type familar in the valgus of adults.

DEFORMITY AND ITS VARIETIES

Deformity in general may be discussed under two heads:

1. That due to gravity or weight-bearing in wholly paralyzed or flaccid limbs. A leg is wholly paralyzed, and in sitting and lying the foot drops into a position of plantar flexion from the

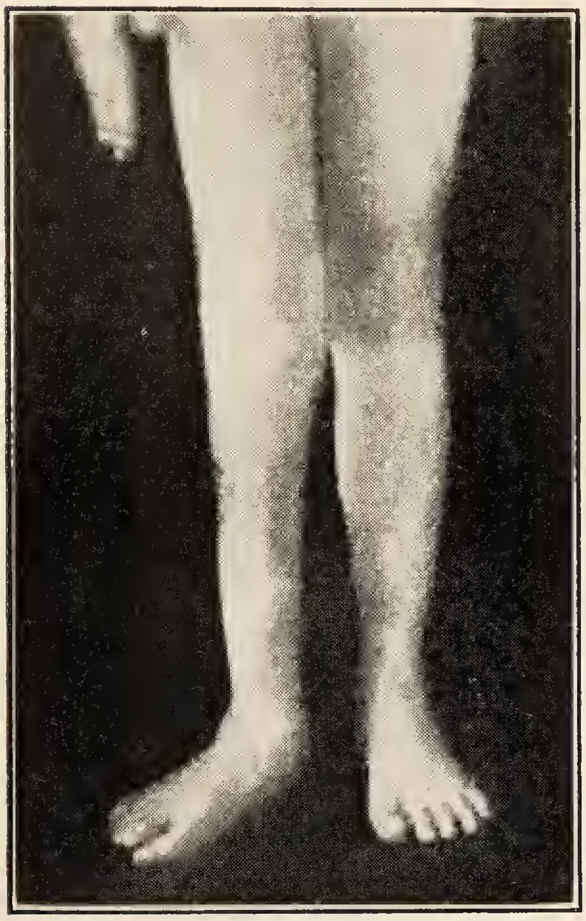

FIG. 29.—Mild talipes valgus from tibial paralysis—right foot.

FIG. 30.—Talipes valgus from tibial paralysis, right foot.

leverage of the unsupported foot. This is the earliest type of distortion to be seen, and exists from the outset of the disease.

If a leg is paralyzed, or partly paralyzed, below the knee without great disturbance of muscular balance, and the patient is able to bear weight on it, the unsupported foot then rolls into a position of valgus, and stretched soft parts become lengthened and shortened ones contracted, making a fixed deformity. Another instance of this type of deformity is to be found in the relaxed and hyperextended knee accompanying cases of extensive thigh and leg paralysis.

In the arm a similar condition is to be seen when a paralysis

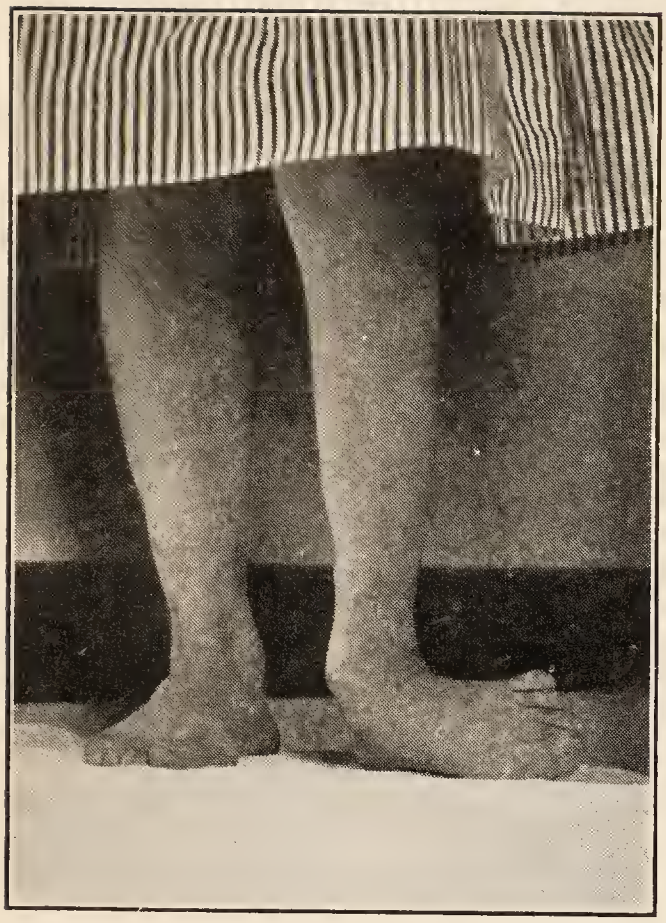

FIG. 31.—Severe talipes valgus from tibial paralysis.

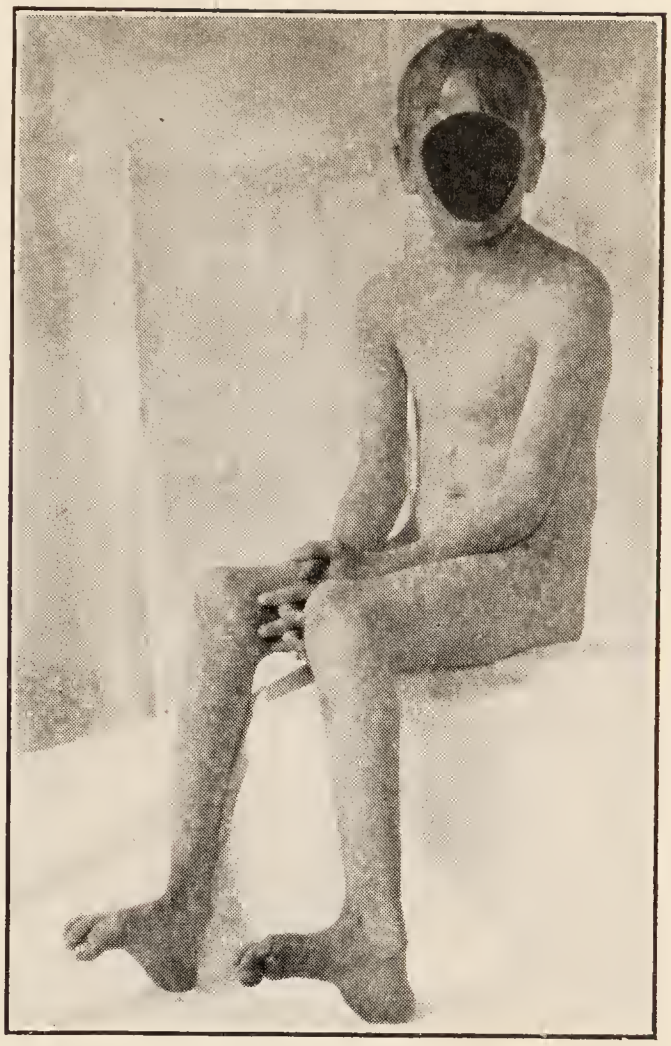

FIG. 32.—Double talipes calcaneus.

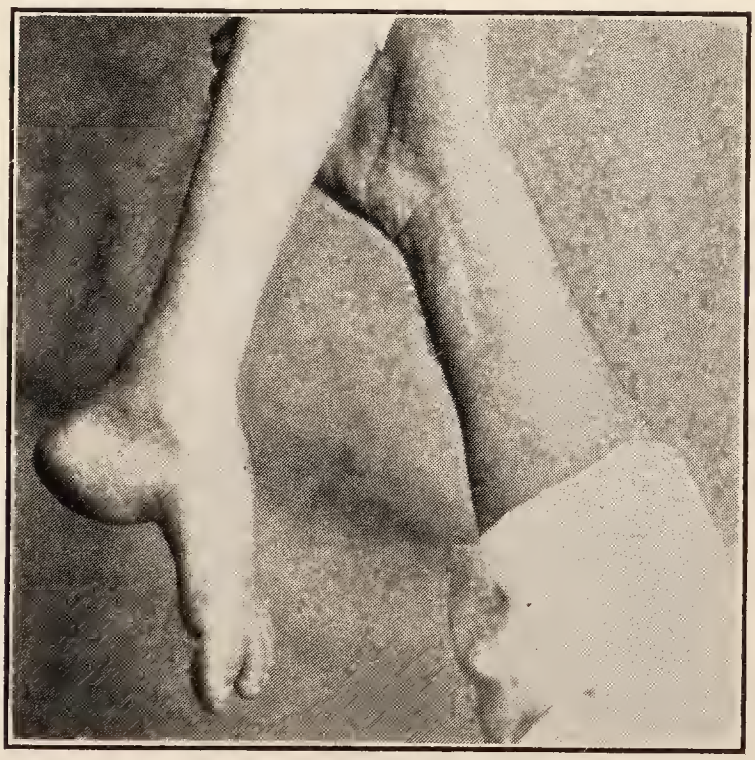

FIG. 33.—Talipes calcaneo-cavus with extensive leg paralysis.

of the arm and shoulder has occurred and the head of the humerus, no longer supported by muscles, is dragged down and away from the glenoid cavity by the weight of the arm.

2. Malpositions due to disturbance in the relative power of antagonistic muscles where paralyzed muscles are overcome by their unaffected opponents.

If the anterior muscles of the leg, or most of them, are paralyzed, and the posterior escape injury, the non-antagonized healthy muscles will by virtue of their tonicity draw the foot into a position of equinus and hold it there, and shortened muscles will, in time, become permanently contracted, although not paralyzed, while lengthened muscles will become permanently stretched, and a fixed deformity will result. It can be predicted in advance, in most instances, what a definite muscular paralysis will produce in the way of deformity. From the study of 635 cases from the Children's Hospital, Boston, the following table of deformities of the foot was formulated:[1]

Deformity.	Resulting from paralysis of
Varus,	Peronei.
Valgus,	Anterior tibial.
	Posterior tibial.
	Both tibials.
	Flexor longus hallucis.
	Whole leg (weakened).
	Complete paralysis.
Equinus,	Anterior muscles, paralyzed or weak.
	Complete paralysis (from dangling).
Equino-varus,	Anterior muscles (with persistence of flexor longus hallucis).
	Anterior and external group.
	Paralysis apparently complete (toe flexors remaining).
Equino-valgus,	Anterior and internal muscles.
	Anterior muscles and weight-bearing.
Calcaneus,	Posterior muscles.
Calcaneo-valgus,	Posterior muscles and one or both tibials.

Other instances of this type of deformity are flexion at the knee and flexion at the hip. In the former the hamstrings are active and the quadriceps weakened, in the latter the hip flexors predominate over the weakened glutei.

[1] Lovett and Lucas: "Jour. A. M. A.," Nov. 14, 1908.

There is one deformity which may belong to either or both of the above classes. This is a fixed deformity of the trunk resulting from an effort to secure equilibrium and is expressed as lateral curvature of the spine. This results from paralysis of some of the muscles of the back, from paralysis of the shoulder muscles and at times from paralysis of the leg which leads to shortening or imperfect function. As a result of these diverse causes, to maintain equilibrium, an asymmetrical position of the spine is necessary, which, in time, becomes fixed. That this is not purely the result of the action of

Fig. 34.—Paralysis of the neck muscles.

unantagonized non-paralyzed muscles is shown by the fact that in paralysis of the muscles of the right side of the back, *e.g.*, the convexity of the lateral curve, is sometimes to the right and sometimes to the left. If this deformity were the result of the action of the non-paralyzed muscles it would always be convex to the same side in the paralysis of the same muscles.

This deformity may occur while the patient is still recumbent and is often evident when the patient first sits up and all cases of infantile paralysis should be examined for scoliosis.

Paralysis of the serratus magnus muscle leads to a curious deformity of the scapula, the so-called "angel wing" paralysis.

The posterior border of the scapula turns away from the spine and is prominent posteriorly under the skin.

With regard to deformity in general and the importance of guarding against persistent malposition the following may be said: If, in standing, the foot rolls over into varus or valgus position, if the knee becomes hyperextended, if the spine curves to one side, these malpositions should be prevented by accurately fitting braces, or corsets, which maintain as nearly as

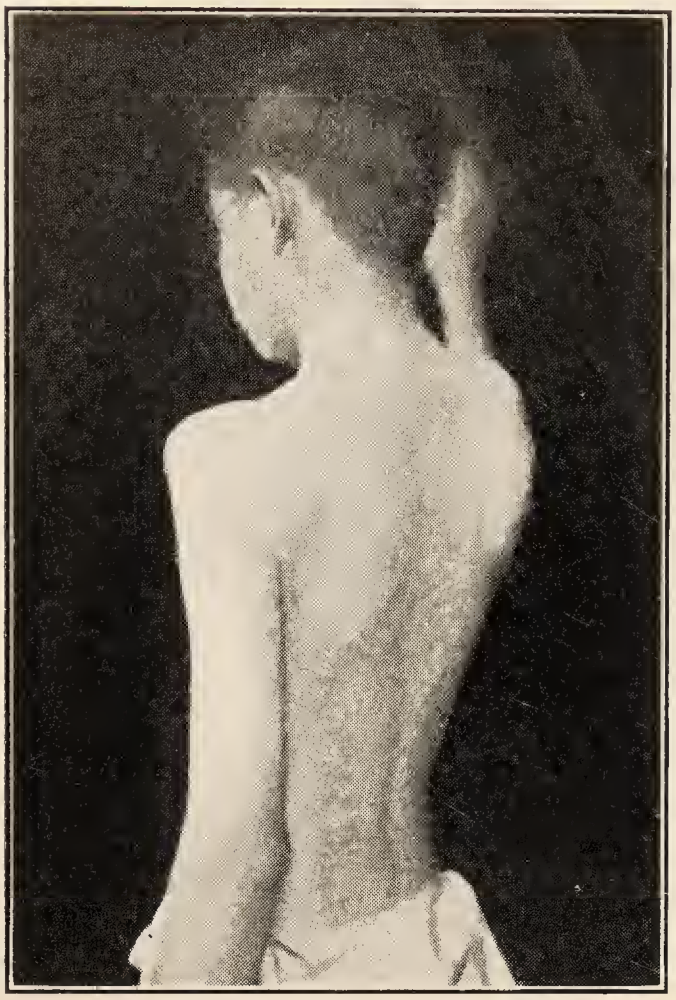

FIG. 35.—Paralysis of right serratus magnus muscle, showing "angel wing" deformity of scapula.

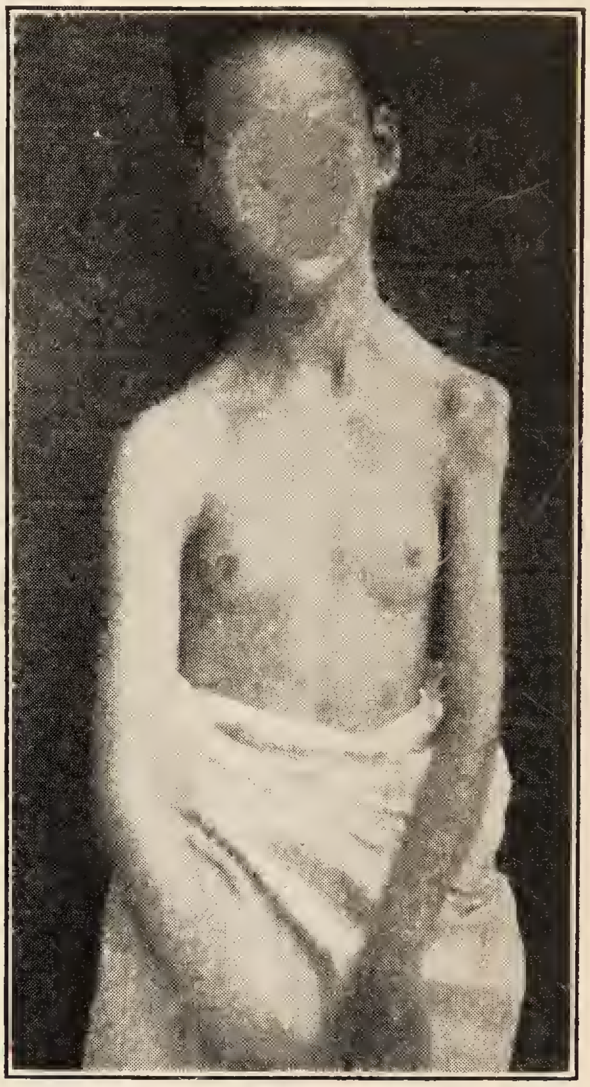

FIG. 36.—Complete paralysis of left arm with dropping of head of humerus.

possible the normal position and the normal relations. The unrestricted use of the muscles in a partly paralyzed leg where such unrestricted use means malposition and unbalanced function is of little importance compared to the harm done. From the point of view of the orthopedic surgeon, therefore, who better than any one else knows the late history of infantile paralysis, the importance cannot well be over-stated of supporting from the outset of the disease, so long as necessary, the

paralyzed limb in its normal position and enabling it to perform, as nearly as possible, its function in its normal relations.

It must be remembered that a muscle may be rendered functionless by prolonged stretching, and that stretched muscles are on the whole more difficult to deal with than are shortened muscles, because stretching is detrimental to the welfare of muscles, and because stretched muscles cannot on the whole be successfully shortened by operative measures.

FIG. 37.—Paralysis of the right deltoid muscle.

FIG. 38.—Mild paralysis of the left arm showing shortening from retarded growth.

In the case of the arm the danger of stretching is of particular importance on account of the frequent involvement of the deltoid muscle. The arm hangs from the scapula supported only by the joint capsule ligaments and muscles of which the deltoid is most important. If the deltoid is paralyzed the head of the humerus tends to drop away from the glenoid cavity and to stretch and elongate the capsular ligament, but especially

to pull on the deltoid and subject it to constant strain from the weight of the arm. It is questionable whether this may not

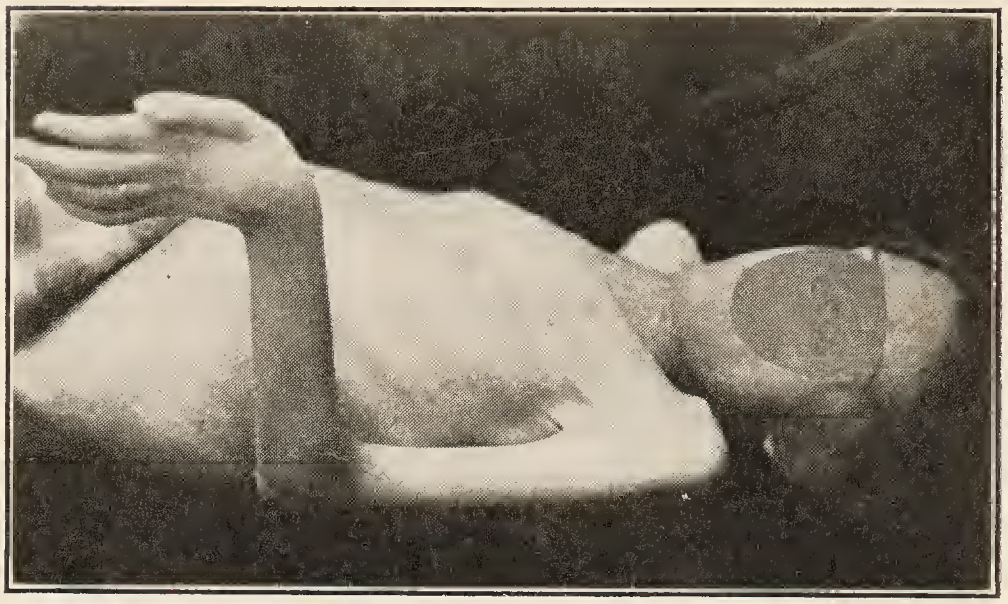

FIG. 39.—Paralysis of left wrist with the hand falling into the position of ulnar deviation induced by gravity.

be the important factor in making paralysis of the deltoid such a formidable and resistant variety.

FIG. 40.—Paralysis of the right arm with supination contraction.

It, therefore, is always desirable to support such arms by a sling taking the weight of the arm off of the shoulder-joint and

it is even a question whether it might not be wise to support the arm at the level of the shoulder at right angles to the body by means of a platform splint to allow the deltoid fibers to shorten. The very unsightly character of the method however will always prevent its general use.

Finally, with regard to deformity a definite rule may be formulated which will be repeated later which deals with a matter of great practical importance often overlooked. *The presence of a fixed deformity is an obstacle to any treatment either by apparatus, muscle training or operation to improve function.* The two questions that of the prevention and that of the cure of fixed deformity are among the most important in the whole subject.

Fig. 41.—Dislocation of the left hip from infantile paralysis.

DISLOCATION OF PARALYZED JOINTS

Dislocation as a result of the paralysis is occasionally met and true dislocation occurs practically only in the hip. The humerus may drop away from the glenoid cavity in severe paralysis of the shoulder but this is not a true dislocation but simply a stretching of the joint capsule and is a gravity deformity.

Paralytic dislocation of the hip, however, is a true dislocation, which is sometimes disabling and it has been somewhat studied. It occurs as a subluxation in which the joint is merely unstable and slips out a little when the leg is adducted or the head of the bone is dislocated quite out of the socket. The most common form is an upward and backward dislocation, the infrapubic or forward dislocation having been reported.

The stretching of joint capsules in infantile paralysis is well known and as the hip-joint is deeply seated it is normally rarely dislocated. When, however, the intrinsic muscles of the hip are paralyzed, the glutei weakened or paralyzed, and the adductors and tensor fasciæ femoris less affected or contracted, the mechanism is at hand for the head of the femur to slip out in adducted positions of the leg. Flexion deformity of the hip is, therefore, to be regarded with suspicion and it

Fig. 42.—Coxa valga and tendency to subluxation of hip due to infantile paralysis. Duration nine years. (*Sever.*)

makes it advisable to relieve these flexion contractions at the hip, where they occur, as early as may be practicable.

The subluxation or luxation is not apparently traumatic but gradually appears and is characterized by instability, shortening and sometimes pain in walking. In one class of cases the dislocated bone forms a new and stable socket for itself and the shortening is the chief annoyance. In other cases the leg becomes much shorter than the other, the head of the femur

fails to make a firm new socket and an exceeding unstable and irritable hip-joint results. Atrophy and practical disappearance of the head of the dislocated femur may occur. When the condition exists which allows a troublesome dislocation of the hip there seems but little to do except to perform an arthrodesis at the hip-joint, an operation to be discussed later. Attempts to hold the hip abducted by a spica of plaster of Paris to enable the capsule to shorten in the milder cases and reduction of the

FIG. 43.—Coxa valga and subluxation of hip of eleven years' duration. The hip was dislocated at every step; a successful arthrodesis was performed. (*Sever.*)

dislocation by a "bloodless" manipulation have, in the writer's hands, always failed, nor is this surprising if one bears in mind what has been said of the mechanism of the production of the dislocation. The remedy of conditions known to favor dislocation is, however, to be recommended.[1]

[1] J. W. Sever: "Boston Med. and Surg. Jour.," Aug. 31, 1911.
Karewski: "Ann. Surg.," 1889, x, 226.
Böcher: "Verhdlg. Deutsch. Ges. f. orth. Chir." Apr., 1909.
Cramer: "Archiv f. orth. etc.," ix, 1, 1910.
Riedinger: "Archiv f. orth. etc.," viii, 111, 1910.

The diagnosis of such dislocations is generally made by feeling the head of the femur slip partly or wholly out of the acetabulum in adducted positions, by shortening of the leg, by elevation of the trochanter above Nélaton's line in superior dislocation and by the x-ray, the most valuable means of all.

Fig. 44.—Recent dislocation of hip from infantile paralysis.

(*b*) RESTORATION OF NERVE AND MUSCLE POWER

Having this discussed the acute phase and its treatment, and having spoken of the beginning of the convalescent phase and the origin and causes of deformity, it becomes necessary to discuss next what measures may be used to preserve and restore the greatest ultimate amount of power to affected muscles. Certain fundamental facts must be noted as a result of the spinal cord lesion, already described. Many

muscles have lost some, and a few muscles have lost all of their power of contraction, and as a result of this, or as the result of an involvement of the trophic centers of the cord, the nutrition and circulation of these parts are impaired.

Fatigue.—The well-being and efficiency of a muscle is largely dependent on the performance by it of a certain number

Fig. 45.—Dislocation of the hip due to infantile paralysis. The head of the femur has gradually absorbed. The case has been under observation twenty years.

of active contractions. When a normal muscle is inactive for any length of time it atrophies. It is an accepted physiological principle that the exercise of the normal functions of a muscle is the best means of increasing its size and strength. It is a well-known practical experience, however, that a muscle may be given so much work to do that weakening and atrophy, instead of strengthening and increased size, will result.

This is to be explained by physiological experiment, which has found that a muscle which has been made to contract until it has reached its fatigue point takes a number of hours to recover its former ability to do work. If, after it has reached the fatigue point, it is still further stimulated, the length of time taken for it to recover is measurably greater, and if the stimulation is continued for some time after the fatigue point, recovery may never take place. The problem then is to find out just how much work is beneficial to the muscle we wish to develop in order that we may avoid giving it the dangerous overdose.

We have been speaking of the development of the normal muscle, but the same rule undoubtedly applies to the partially paralyzed muscle, except that in the case of the latter the danger of overwork is much greater.

Aside from this theoretical consideration it has been found in practice that overwork of muscles weakened by infantile paralysis is seriously detrimental and retards recovery. Clinical observations were confirmed by the muscle test especially in cases in private practice watched by frequent tests. It has been found by these tests that many paralyzed children who were doing very little in the way of walking were obviously damaging their muscles. Indeed it has been difficult to realize that so little walking could do harm, but as these patients have been more and more restricted in activity the rate of improvement has been faster. In the writer's opinion one of the serious defects of treatment is that patients are encouraged to do too much, are allowed too much activity and frequently receive too much therapeutic exercise and massage. It is apparently desirable that patients in their first year of the disease should get about and become accustomed to the upright position; it is essential for good progress that they should have therapeutic muscular exercises to develop weakened muscles and establish new paths from brain to muscle. Fatigue to weakened muscles is dangerous and detrimental and underuse of such muscles is safe. The avoidance of fatigue must be insisted on as an essential to the best progress no matter what restriction of activity

it may mean. A quotation from a paper of the writer's may make the matter more specific.

It has been repeatedly observed in my private practice that power might begin to return in a very faint degree to a muscle while under muscle training, and that with care this power would steadily increase, but if that muscle were exercised even very gently every day, that power would diminish or disappear, so that we exercise such muscles only once in three days at the outset, increasing the work most carefully. . . .

Illustrative cases seem to me to show that much smaller degrees of overuse may be deleterious than is generally supposed. Probably any of us would agree that gross and persistent overuse of partly paralyzed muscles would be undesirable; but it seems to me reasonable that in the early stage of returning power, we should be exceedingly careful in the use of muscles in walking and in the use of heavy and prolonged massage, much more careful than we are at present, if I may judge the practice of others by my own previous methods.

This matter was confirmed and made more definite by the muscle test. Illustrative cases follow:

Case 1.—A boy of five, in the Vermont series with the onset in 1914, was having at the time of the first test one and one-half hours of massage and one hour of muscle training daily. This was changed, and he was given one hour only of gentle muscular exercise, and the second observation showed a substantial gain of strength in all affected muscles, an illustration of the effect of too much treatment.

Case 2.—A boy with the onset in 1914, in July showed partial paralysis of the left arm. He then began to milk ten cows daily, and in a month had lost strength in all of his left arm muscles except the biceps and triceps, which had gained slightly. The loss was greatest in the muscles of the forearm, which were of course those most exercised in milking, an illustration of the effect of overuse of the muscles as a cause of loss of power in the overused muscles.

Case 3.—A man of twenty-two was referred in the fourth week after his onset. He had involvement of the right leg and arm, walked with a limp and could not raise his right arm. The left arm appeared to be slightly weakened. Examination by the usual method showed extensive weakness in the left arm, very little power in the right deltoid, and a general involvement of the right leg. His right arm was put in a sling, he was cautioned against much walking and the use of the arm, and weekly muscle tests were made, showing a general slow gain, but no therapeutic exercises were allowed at first. At a test, October 4, an increase of 50 per cent. in the power of the right gastrocnemius muscle was observed, and on questioning it was found that he had been daily rising on his toes as a trial. This seemed to indicate that he was ready for therapeutic exercise, on which he then began with success. The test, October 26

showed a loss of 25 per cent. of power in the wrist and finger flexors of the right hand, and it was found on questioning that he had been writing too much. This was stopped, and on the following week a return of the former power was found in these muscles, an instance of the information afforded by the test in directing routine and defining treatment.

CASE 4.—A girl aged eight and one-half, affected in 1913 with extensive paralysis of both legs, was walking with splints and crutches, and her muscle power was on the increase under daily muscle training. Nov. 18, 1915, there was a general loss of power in the legs. On questioning it was found that relatives had been visiting the family, and the child had been doing much more than usual, an instance of the deleterious effect of local and general fatigue.

The therapeutic measures to be considered at this stage are:

(*a*) Massage.

(*b*) Heat.

(*c*) Electricity.

(*d*) Muscle training.

(*a*) **Massage.**—The favorable action of massage on parts affected by infantile paralysis is undoubted and is to be recognized but also it must be recognized that it has distinct limitations and that too much must not be expected of it. The proper stroking, kneading and manipulation of an affected limb stimulates the flow of venous blood toward the heart by mechanical emptying of the veins, which incidentally increases the flow of arterial blood to the limb to replace the venous blood carried away. Massage also facilitates the flow of lymph toward the center of the body by mechanical emptying of the lymphatics. Direct manipulation of the muscles also must in a measure empty them of waste products retained in the muscles themselves. These measures all tend to improved circulation of blood and lymph in the affected parts and consequently to improved muscular nutrition and tonicity of the muscles massaged, and thus probably retard and diminish muscular atrophy by inducing better nutrition locally. On the other hand, the overuse of massage, *i.e.*, the use of too long or too rough manipulation, causes muscular fatigue, increases muscular atrophy and diminishes muscular tone.

It therefore can only be expected of proper massage that it will improve locally muscular tone and nutrition and antagonize

muscular atrophy and nothing more. It will not restore muscular power except in this way and it has no direct effect on the disease nor on the transmission of nerve impulses from brain to muscle.

Vibration should be classed as mechanical massage and is given by means of an apparatus which produces locally a succession of rapid blows to the tissues. It apparently is effective chiefly by acting on the vasomotor nerves which are stimulated to bring more blood to the part. It is also probable that the direct mechanical effect on the muscle of a series of blows is not to be neglected because it is well known that a blow to the belly of a muscle causes a contraction of the fibers. A succession of mild blows would therefore probably tend toward increasing muscular tonicity which is of course desirable. Practically vibration in connection with massage seems to make the latter somewhat more effective.

(*b*) **Heat.**—If a partly paralyzed limb is heated it is capable of performing better muscular function than before. This is due apparently to two causes: first, to an elevation of the temperature of the muscles to a point more favorable to muscular activity; and second, to a stimulation of the circulation. Muscles work better the higher the temperature up to the point of injury from heat. The maximum temperature limit of normal life may be put at about 116°F. and heating the muscle has a direct specific effect upon its activity.

Moreover, the heat causes a reflex dilatation of the surface capillaries in the skin which causes a flush and draws the blood out of the deeper parts. This is succeeded by a contraction of surface capillaries and a dilatation of deeper vessels so that the flow of blood in the affected limb is stimulated and this also adds to temporary muscular effectiveness.

But apart from its use above, the heating of the limb apparently adds to the effectiveness of massage because if the massage is given directly after the heating while the superficial capillaries are full of blood, a greater volume of blood is probably driven toward the center of the body to be replaced by a similarly large volume returning to the limb.

Heat may be applied as radiant heat or non-radiant heat.

Radiant heat is given off from electric light bulbs with carbon filaments arranged in some reflecting cone or hemisphere. This form of apparatus is simpler, and more easily handled than the various hot air ovens and does not require preliminary heating. Whether radiant heat possesses more desirable qualities than non-radiant heat is not established.

Where special apparatus is not available an ordinary oven or even open fire may be utilized to warm the limb. In a large sheet of asbestos board a hole is cut and the leg put through the hole into the moderately heated oven or close to the open fire, the sheet of asbestos board protecting the patient from the heat.

Hot water is a less desirable form of heat, as it makes the skin tender and cannot be borne at so high a temperature as can the dry heat.

If the process of heating is too long continued the reaction fails to occur, so that ten to fifteen minutes is long enough. The temperature may be as high as the patient can bear without discomfort.

In virtue of the fact that muscles perform better function when warm, the paralyzed limbs should always be warmly clothed. Heavy stockings and long undergarments should be worn in the winter. An arm may be wound in cotton wadding or an extra sleeve may be used. Chilling of the affected parts is always bad and children using wheel chairs in winter should not only be warmly protected with rugs but the feet should rest on a hot water bottle.

(*c*) **Electricity.**—Electricity has been in the past very extensively used in the treatment of infantile paralysis and today, although the subject of much controversial argument, it has been until recently at least, probably the most generally used form of treatment, especially in the hands of the general practitioner. The reason for its general use has seemed to consist in a general impression that it would do good in some mysterious way not clearly formulated. But a closer analysis is necessary if one is to arrive at any estimate of its value.[1] Several kinds of electricity are advocated.

[1] Sachs: "Jour. A. M. A.," Nov. 5, 1910, p. 1663.
Diller: "Jour. A. M. A.," Oct. 22, 1910.

The *faradic* current acts directly on the muscle to which it is applied to produce a local contraction. If the muscle is not wholly paralyzed this takes place and is theoretically of benefit when contraction of a given muscle cannot be produced voluntarily. But it is evident that it is not a very powerful means of exercise and practically it is disagreeable to the patient, and to young children a source of terror. It seems as if it were a legitimate means of giving to certain muscles a mild contraction repeated a few times, but that it can be regarded only as a means of gentle occasional exercise and too much must not be expected from its use.

The *galvanic* current, on the other hand, is used to improve nutrition, to promote the conduction of nerve impulses, and for an indefinite general effect on the nervous system which its advocates believe it to have. It is obvious that the matter of proving this is not easy, if possible at all, and one must judge largely if not wholly empirically. In this case personal experience must be drawn on and the writer has never been convinced in trials lasting over many years that galvanic electricity was of the least use in any individual case. It has been repeatedly used on a patient's right or left side in cases of symmetrical paralysis and the assistant who was giving daily muscular exercises and massage was not told which side was receiving the electricity and at the end of two months she has been asked if she had noticed a different rate of improvement on the two sides and if so which side showed most. In no instance has the side treated by electricity showed a faster rate of progress. It has not been possible as yet to test out the progress of cases thus treated by means of the spring-balance muscle test.

But aside from galvanic and static electricity of late the newer forms of current have been advocated, such as high-frequency, the sinusoidal currents, the Morton wave current, etc. The working of these and their rationale is even more obscure than in the case of the galvanic current.

The reasons for the use of the high-frequency current for example are given as follows:[1]

[1] Frauenthal and Manning: "Infantile Paralysis," F. A. Davis, Philadelphia, 1914.

> "I cannot attribute the results obtained wholly to the vasoconstrictor action of the high-frequency current and consider that the blood-vessel walls are rendered less permeable, and that the transudation of fluids and the migration of cells are checked by a direct oxygenating and vivifying influence of the venous blood. I consider this oxygenation of sufficient power and extent to partly or wholly sterilize the invaded tissues in a similar manner to the electric sterilization of water."

and with regard to electric stimulation in general:

> "Electrical stimulation of the ganglionic neuron through its peripheral branch directly improves local nutrition, increases the caliber of the nerve of conduction, manifolds energy transmission thus securing compensation for the decrease in muscle mass."

Those persons to whom this type of physiology and pathology appeal will find no difficulty in satisfactorily explaining the benefits likely to be received from the use of electricity.

It can only be repeated that the evidence that such forms of electricity are of benefit rests at present almost wholly on the statements of personal experience.

There is, however, some purely experimental evidence that electricity retards loss of weight in denervated muscles. Langley and Kato in 1915[1] published the results of some experimental work dealing with the rate of loss of weight in muscles after nerve section with observations on the effect of stimulation and other treatment.

It was found that stimulation of a denervated muscle through the skin caused only the superficial fibers to contract unless strong currents were used and the experiments tended to show, "although they were not numerous enough to give decisive results," that electrical stimulation with condenser shocks delays the atrophy.

> "It is practically certain that if electrical stimulation has a beneficial effect, the optimal effect will be with that current which is strong enough just to cause contraction. In the ordinary methods of stimulating muscles through the skin, whether by unipolar or bipolar methods, with currents of long or short duration, the intensity of the current is much greater in the superficial than in the deep fibers, and we think it doubtful whether the latter can be stimulated without using currents injurious to the former."

[1] "Journal of Physiology," xlix, p. 432.

These observations it must be remembered were made on denervated muscles and not on those affected by infantile paralysis.

With regard to the generalizations made as to the use of electricity, it must be remembered that practically all cases improve after the acute attack is ended, that 25 per cent recover spontaneously in four years (Massachusetts State Board of Health figures) and that no one can foretell in a given case how rapid or how slow the improvement will be. Under these circumstances loose generalizations as to any form of treatment are likely to be misleading and only closely checked quantitative observations on muscular strength or a very extensive clinical experience with all methods would make such generalizations of any value.

Electricity used in proper doses probably does no harm locally and perhaps some good, but it often does harm by making the parents and the practitioner believe that the patient is being efficiently treated while the other important and really useful means of treatment are being neglected. In this way electricity has done an indefinite amount of harm by taking the place of other measures during the critical period of convalescense. The use of too strong electricity may be detrimental. In short, the belief of the writer founded on experience of treatment with and without electricity is that faradism is a means of inducing mild muscular exercise, and possibly in that way somewhat useful. That galvanic electricity and the newer currents have not been proved to be of value and in his experience have not appeared to be of any value whatever, but in his opinion when, parents have heard of the wonders of electrical treatment and desire to use it they should be encouraged to do so *provided* they use at the same time the other treatment, the value of which is universally admitted.

(*d*) **Muscle Training.**—The importance of muscle training and of the muscular examination leading up to it is so great that these subjects will be considered in a chapter by themselves (see page 123).

CHAPTER IV

TREATMENT

THE CHRONIC PHASE—SHORTENING—LAMENESS—CORRECTION OF DEFORMITY—DEFORMITY AT THE ANKLE—DEFORMITY AT THE KNEE—DEFORMITY AT THE HIP—SCOLIOSIS—DEFORMITIES OF THE UPPER EXTREMITY

In the chronic phase the tendency toward spontaneous improvement may be assumed to be slight, although the Vermont figures have shown that it goes on much longer than had been commonly supposed. It is the stage of stationary paralysis and the time when fixed deformities become evident and when the operative question arises. The mechanical needs of the paralyzed limb from a therapeutic point of view are much the same as they were before and the patient with a paralyzed quadriceps muscle will still need a brace, and the advisability of massage and muscle training still exists although holding out less favorable prospects than in the previous phase. It is a stable state of affairs when we can quietly decide what is best to be done, one need not wait longer.

The treatment in this stage has in late years very properly become much more operative than it formerly was on account of the rapid development of this very promising field in orthopedic surgery and this development has changed the outlook for many paralyzed patients. But it must always be borne in mind in this matter that the most experienced operators in this line of work in all parts of the world advise against operation in less than two or three years after the acute attack except for minor tenotomies, etc.

SHORTENING

This is an important matter frequently overlooked in the treatment of cases at this stationary stage of the disease, a matter which demands close attention if one is to obtain the best results in paralysis of the leg from any treatment.

Where shortening exists to any degree it is desirable to estimate and correct it by building up the short leg. It is undesirable for the growing child to be standing with the pelvis always inclined obliquely and a consequent lateral spinal curve, as must be the case when one leg is decidedly shorter than the other. Moreover, to walk with much shortening throws the muscles of locomotion out of balance, and in addition to the ungainly walk is in some cases detrimental to some of the muscles about the hips. Shortening of a quarter of an inch is of no importance, but when it gets to be more than half an inch it is generally desirable to correct it at least in part by raising the sole on the shortened side. As a rule the full correction is not well borne, at least at first, and one must experiment to find out just the amount with which the patient walks best. The question of shortening is entirely independent of whether or not a brace is worn and is as important after an operation as before it.

LAMENESS

At this stage the lameness will have become fixed and characteristic and this subject is considered in another place in connection with the examination preliminary to muscle training (page 123).

OPFRATIVE TREATMENT

This is properly undertaken for two conditions: (1) the correction of fixed deformity; and (2) the improvement of function. These will be next considered in the order named.

THE CORRECTION OF DEFORMITY. PROCEEDINGS OPERATIVE AND OTHERWISE

The term fixed deformity applies to a condition where a joint cannot be moved passively through its normal arc, that is where there is some restricting limitation to full motion.

A general rule of much importance has been stated to the effect that *no treatment mechanical or operative should be undertaken till fixed deformity is relieved.* . This, of course, does not apply to operations undertaken for the cure of deformity.

In general, stretching of contracted tissues is preferable to cutting them as it better preserves muscular balance. To cut a tendo achillis, *e.g.*, means that after recovery the muscle will have a longer tendon and shorter belly than before, whereas if the same lengthening is obtained by stretching, the proportion of belly and muscle are preserved. This consideration, however, in no way militates against cutting operations when they are necessary. Simply, if stretching will do the same as cutting, even if it takes longer, it is better.

The individual fixed deformities will next be considered and discussed.

DEFORMITY OF THE ANKLE

Equinus.—This is of all the deformities of infantile paralysis the most frequent not only because at the ankle the paralysis is more common and more severe than elsewhere in the body but

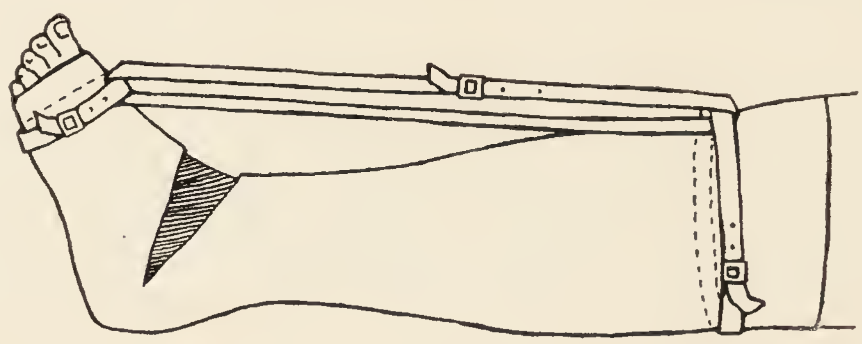

FIG. 46.—Method of stretching contraction of the tendo Achillis.

because during the acute attack the child is too often allowed to lie with the bedclothes holding the foot in plantar flexion, and in sitting the foot hangs and continues in this same position of dropping. Under these conditions an adaptive shortening or a shortening due to muscular contraction occurs, in which the posterior muscles become contracted and the anterior muscles stretched. This deformity may occur in the first weeks of the acute attack, and from the onset should be guarded against. When it has become fixed it constitutes a serious obstacle to standing and walking, and requires correction before mechanical or other treatment is likely to be successful.

A new means of correcting it, which has proved most efficient, is to put on a plaster-of-Paris circular bandage reaching from the toes to just below the knee. In putting this bandage on

the leg is fully flexed on the thigh in order to relax the gastrocnemius muscle and allow as much dorsal flexion of the foot as possible. When the plaster has become dry which takes about twenty-four hours, an elliptical piece is cut out over the front of the ankle joint in the flexure between the foot and the leg, embracing about two-thirds of the circumference of the cast at this point. A webbing loop is then put around the foot and another around the top of the cast, and these two webbing loops are connected by another webbing strap furnished with a buckle, by which continued tension may be made upon the foot, pulling it into dorsal flexion with any desired degree of eversion or inversion of the sole. In recent cases this method of treatment will correct the deformity often in five or six days, and in older cases often within two or three weeks. It is surprising what degree of equinus may be corrected by this method without much discomfort, but occasionally a case proves utterly resistant to the method (Fig 46).

Operative Measures.—With regard to operative measures for equinus, these should be undertaken with great care for two reasons. In the first place a patient with equinus and with poor anterior muscles is likely to have after tenotomy a worse foot than before, because if the anterior muscles do not have any power to regain, the foot becomes flail-like and is often of less use after operation than before because it is loose in both plantar and dorsal flexion. It is therefore a sound rule *not* to divide the tendo achillis in paralytic talipes equinus unless there is evidence of fair power in the anterior muscles, or unless an anterior silk ligament is put in to prevent foot-drop. A second caution of equal importance in this connection is that with a weak quadriceps it is, as a rule, poor surgery to divide the tendo achillis when talipes equinus is present, because a patient with a weak quadriceps and a mild equinus can walk without a brace, the knee locking back and the quadriceps being thrown out of action, whereas if the equinus is removed the patient will be unable to walk without a brace. It is therefore again to be recommended most carefully that tenotomy for paralytic talipes equinus should be done only with great care and in accordance with the restrictions given above.

If an operation is desirable it is a matter of no consequence whether the tenotomy is a simple subcutaneous tenotomy or one of the more elaborate tendon lengthenings such as the Bayer operation. If a tenotomy is performed, after operation the foot should be placed at a right angle to the leg and put up in a plaster-of-Paris circular bandage, and kept in this position for preferably six weeks. This unusually long time is mentioned in order to allow the stretched anterior muscles to recover such power as they may, and to have an opportunity of becoming shortened. It is a common experience in properly selected cases to find a very decided improvement in the power of the anterior muscles after tenotomy.

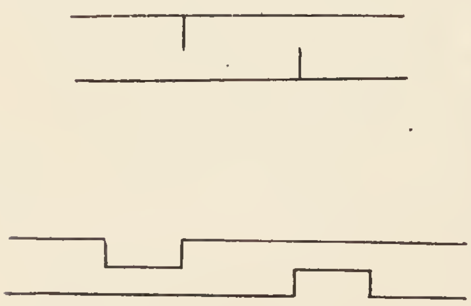

FIG. 47.—Bayer's plastic tenotomy.

Other Deformities of the Foot.—With regard to talipes varus and valgus, that is, the inverted and everted positions of the foot which occur occasionally in infantile paralysis, the simple correction of the deformity by tenotomy or manual force is of no special use, because it will recur again from the same causes which made it occur in the first place. The correction of deformity here should figure in most cases merely as a preliminary to some operative procedure intended to prevent a recurrence of deformity.

It has been said earlier that tendon grafting and similar operations should only be undertaken in a foot whose deformity has been corrected. It is possible in most cases to correct the deformity at the time of operation before doing the tendon grafting or similar procedure. In other cases where the deformity is very severe it seems wiser to perform the operation in two separate stages at different times. These two stages are (1) the correction of the deformity, and (2) the tendon transplantation or other procedure.

The correction of the deformity would be accomplished by manual force, supplemented or not by tenotomy or fasciotomy. The foot would then be allowed to recover from its traumatism after which the tendon transfer may be performed. If an astragalectomy, arthrodesis or other operation involving the

removal of bone be decided on the deformity can be corrected at the time of the bone operation.

DEFORMITY AT THE KNEE

There are three deformities found at the knee in infantile paralysis: (1) flexion deformity, (2) knock-knee, and (3) hyperextension of the knee.

Flexion Deformity.—With regard to flexion deformity, this is due to the predominance of the flexor muscles over the extensors, with the contraction of the knee in a bent position as a result. This deformity may or may not be accompanied by

Fig. 48.—Severe infantile paralysis of nine years' duration. Attitude in lying showing severe scoliosis. There is also present contraction of both hips, both knees, double knock-knee, severe equinus of one foot and paralysis of one arm. Never treated.

talipes equinus and hip flexion although the association is frequent. It may occur early in the disease, in this case generally being acquired during the tender stage, or it may appear later as a result of the predominance of the posterior muscles.

It is less frequently necessary to do a cutting operation in this deformity since the method of wedging was adopted. In this proceeding a circular plaster is applied to the leg in the deformed position, reaching from the groin to the toes. It is made rather heavy over the knee, and after it has dried, a transverse division of the plaster is made at the level of the knee covering the posterior two-thirds of the plaster, that is to

say, a transverse division of the plaster on its posterior aspect. This opening is then wedged open by a thin piece of wood, such as a throat stick, and the wedging is then progressively increased until the knee is straight. If done with care the proceeding is attended by very little pain or discomfort. Recent deformities of the knee can be corrected in a few days, and the moderately serious ones within three or four weeks as a rule. The severe and long-standing cases will require many weeks but some prove resistant to full correction by this method.

This method is preferable to attempting to stretch the knees by means of a splint. In case of a very resistant deformity, which would be uncorrected by this means of stretching, division

FIG. 49.—Front view of case seen in Fig. 48.

of the hamstring tendons would be required, which should be performed by the open incision rather than by subcutaneous tenotomy.

Attempts at forcible straightening of such flexed knees under anesthesia without cutting tendons are well enough in the more recent cases with no great deformity where wedging cannot for any reason be carried out. But in cases of marked flexion which are of moderate or long duration it must be remembered that there is some subluxation of the tibia on the femur due to the continual pull of the hamstring muscles, and that a forcible straightening alone, is likely to produce a straight leg with the tibia in a line posterior to the femur, in other words, in a position

of subluxation. This is less likely to occur in the wedging process because the posterior muscles apparently yield slowly and are thus less likely to cause subluxation (Fig. 52).

It is well to remember that in severely flexed knees of long duration, a knock-knee may appear when the leg is straightened. Knock-knee is never evident in a flexed knee, being a deformity only of the lower articular surface of the femur and not of its posterior surface. So that in the flexed position such deformity is not present but may be very evident when the knee is straightened by any of these methods.

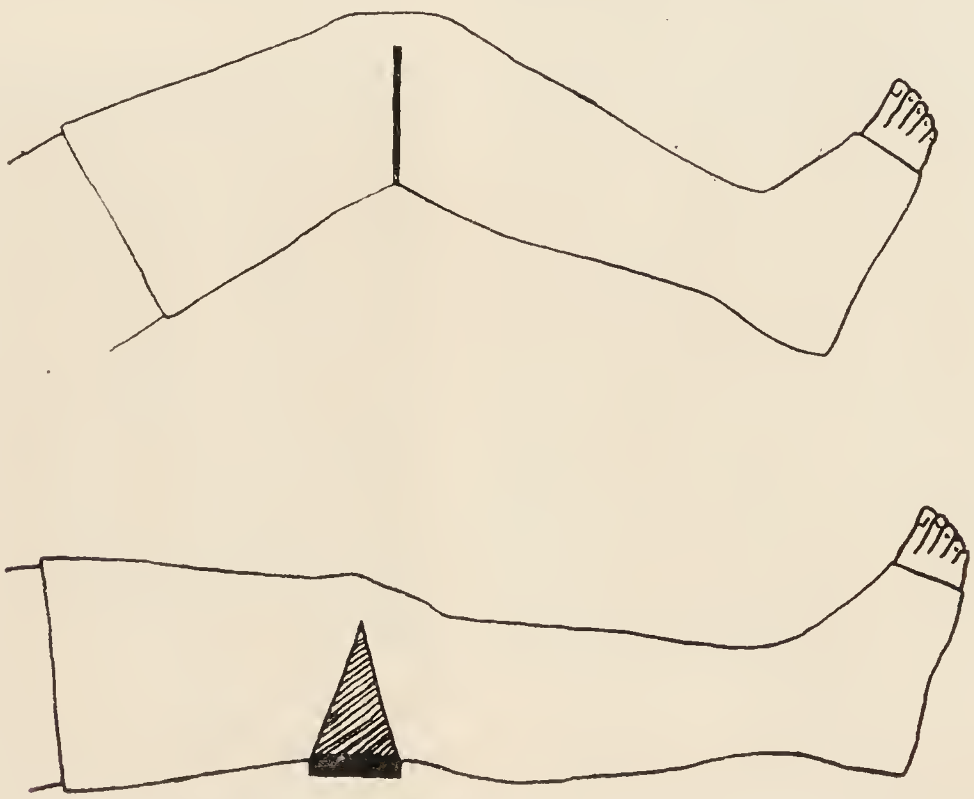

Fig. 50.—Method of wedging knee for flexion contraction.

In severe and intractable cases of knee flexion of many years standing with marked bony deformity an *osteotomy* above the condyles may be necessary but never should be performed before adolescence.

Knock-knee.—With regard to knock-knee, children with extensive infantile paralysis of the legs are likely to acquire a knock-knee, the mechanism of which has never been quite clear. This knock-knee does not in its end result differ essentially from the knock-knee of rickets except in its etiology. It is not only unsightly, but if it becomes very severe is likely to make the use of splints difficult on account of the internal prominence of the knee. In younger children this can be controlled and perhaps cured in the milder cases by the use of a splint pressing

outward upon the inner condyle of the knee. In cases of longer standing, where it becomes a serious disability, Macewen's osteotomy may be done just as in rachitic knock-knees. This consists in partial division of the lower end of the femur from the inner side just above the inner condyle of the femur, and by means of reasonable force fracturing the knee into a straight position. The difficulty about the operation is that

Fig. 51.—Severe double knock-knee from old infantile paralysis. Most marked on left side.

Fig. 52.—Knee formerly contracted in flexion and straightened under ether showing subluxation of tibia persisting.

the circulation and the innervation in cases severe enough to have acquired a knock-knee of this grade are none too good, and although fractures unite perfectly well, it would mean a long disuse of the leg and possibly some impairment of function. It is on the whole a proceeding not to be lightly undertaken, but perfectly proper if it becomes necessary for function.

Hyperextension of the Knee.—If this deformity, which is generally due to paralysis of the quadriceps muscle combined

with weak or paralyzed hamstring muscles, is allowed to persist uncorrected, the knee not only bends further and further

FIG. 53.—Hyperextension deformity of both knees from double quadriceps paralysis.

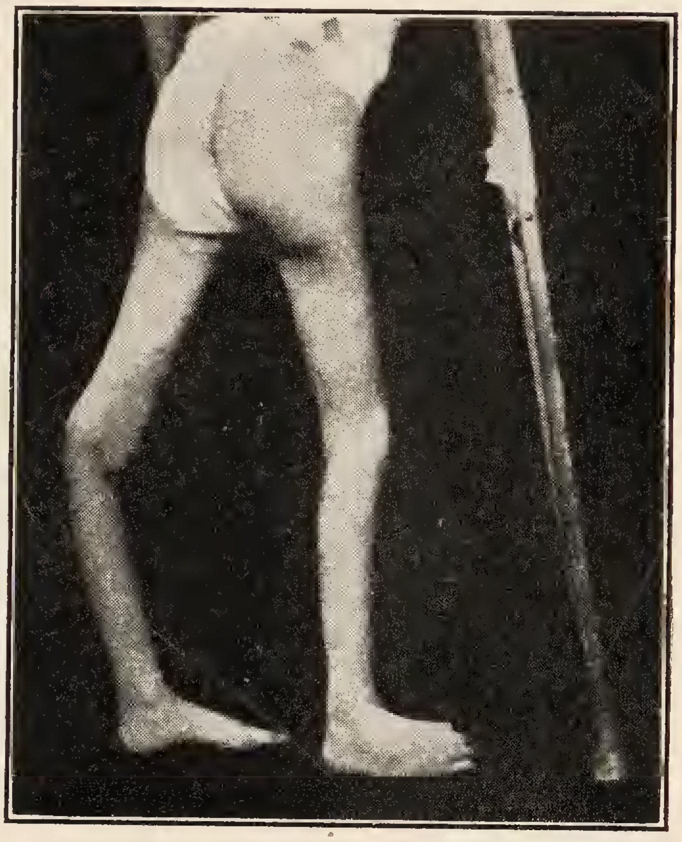

FIG. 54.—Hyperextension deformity of left knee from quadriceps paralysis.

FIG. 55.—Flexion deformity of both hips.

backward but becomes loose laterally. No operation short of arthrodesis, which is generally undesirable, is of any value, but the use of a brace to prevent hyperextension of the knee is

desirable. In cases where in walking the knee hyperextends even to a slight extent the use of a brace, such as the caliper described with a posterior strap, checking hyperextension is desirable and, if constantly worn, slight cases of hyperextension weakness may often be cured of the deformity. If not treated such hyperextension may reach a high degree as shown in the illustrations.

DEFORMITY AT THE HIP

Probably the most troublesome deformity except scoliosis in infantile paralysis consists of a flexion deformity of the hip due to a contraction of the tensor fasciæ femoris muscle, which may

Fig. 56.—Extensive paralysis of both legs with flexion contraction at hips and knees and extreme double talipes equinus.

exist alone or with flexion deformity of the knee and equinus of the foot. In these cases the thigh cannot be extended fully upon the body either actively or passively because of the flexion deformity in the hip, and the correct upright position becomes impossible either with or without braces. If the child lies on the back and the knee is straightened and made to touch the table, just as in tuberculosis of the hip with ankylosis in flexion, the lumbar spine rises and the patient allows the knee to come to the table by means of an extreme lordosis. If the leg is again raised, the back comes flat on the table. The deformity, however, is a combination of abduction and flexion, so that if the leg is abducted at the same time that it is fully extended less resistance is encountered. This is a source of much inaccuracy in treatment and diagnosis, because it must be remembered that to estimate fully the degree of flexion present

the leg must be extended in the long axis of the body and not in an abducted position.

When the deformity coexists with flexion of the knees and plantar flexion of the feet it is a crippling affection preventing the patient from standing erect, and the hip element is the hardest of the three to correct. When the hip deformity exists alone in a moderate degree the patient can stand erect but with a greatly inclined pelvis and a severe lordosis, because this is necessary in order to get the feet to the ground.

Fig. 57.—Contraction deformity at left hip with contraction of left knee in flexion, talipes equinus of left foot.

Fig. 58.—Contraction deformity of left hip showing position in standing with increased lordosis.

Treatment by Stretching.—The deformity in many instances, even in some cases of many months' duration, can be removed by prolonged stretching, but operation is simple, so that except in young children the discomfort and prolonged recumbency of the stretching hardly seem worth while.

If stretching is attempted the patient should have traction on the affected leg or legs and lie on a bed frame. The pelvis

is gradually raised until it has reached a conisderable height, so that the pull comes in hyperextension. In spite of the fact that the back arches up, this method is fairly efficient in removing the deformity in the milder cases, especially in recent ones in young children. It is a matter of several weeks as a rule.

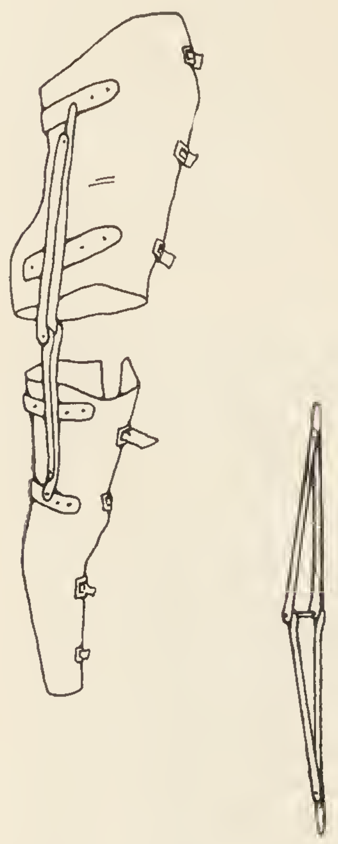

Fig. 59.—Plaster apparatus for stretching hip flexion contraction. The small figure shows the detail of the hinge seen from the side.

Or an apparatus may be used for stretching the deformity, which attacks it directly and which seems surprisingly efficient in the cases in which it has been used. It consists of a plaster jacket with a carefully moulded pelvic part and a plaster leg. These are hinged together opposite the hip joint on the affected side, and the hinge is a double one reinforced by a truss, as shown in the illustration. The abduction tendency is so great in extension that unless the hinge is very strong and protected against abduction the iron will be bent as the leg comes down and the apparatus thus become ineffective on account of the abduction of the extended leg. With this hinge, which holds the leg in the same plane all the way down, it becomes effective upon the contracted tissues in many cases of moderate grade and fairly long standing.

Operation for Hip Flexion.—In former times a very unsatisfactory transverse myotomy was the only means at our disposal for the correction of this deformity. It consisted simply in a muscular division below the anterior superior spine, often going down very deep, even to the division of the psoas tendon, and this was followed by prolonged rest in bed with hyperextension. The operation was most unsatisfactory, relapse occurred in the majority of cases, and it was a bloody and extensive operation if effectively performed.

An effective, simple and safe operation has been devised by Soutter,[1] which rests on an entirely different basis and which is thoroughly efficient even in severe cases. It is sound in

[1] Robert Soutter: "Boston Med. and Surg. Jour.," clxx, No. 2, Mar. 12, 1914.

principle because it lowers the muscular origin of the tensor fasciæ femoris instead of dividing its fibers, so that relapse seems unlikely and has not occurred in any of the writer's cases nor in any case known to him.

A longitudinal incision two or three inches long is made midway between the anterior superior spine of the ilium and the trochanter. The tensor fasciæ femoris is exposed and divided by a transverse incision as far back as the trochanter, reaching forward to the anterior superior spine. This opens slightly, but does not give much correction. With an osteotome the

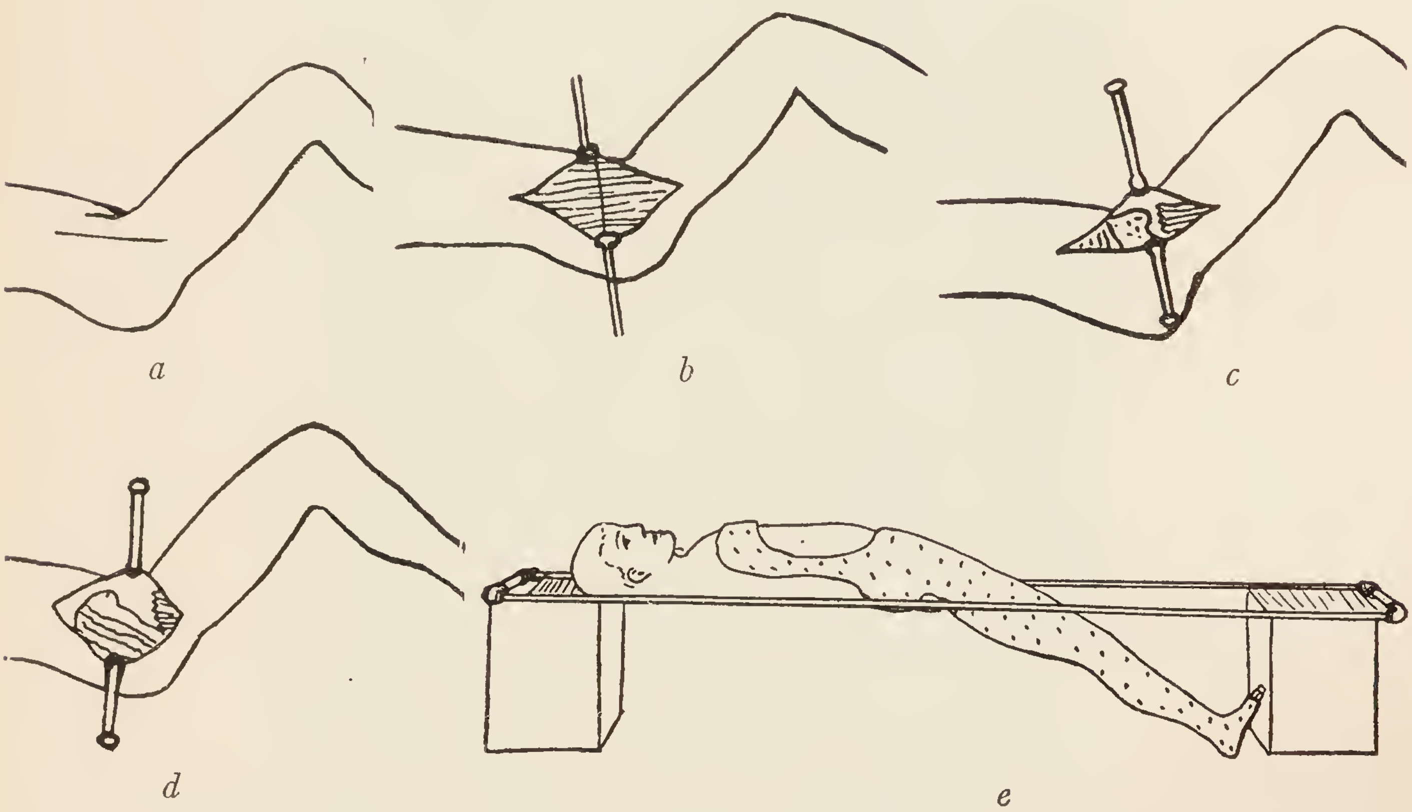

FIG. 60.—Fasciotomy for flexion deformity of hip. Soutter's operation. (*Soutter.*)

periosteum from the anterior superior spine of the ilium is loosened, including the cartilaginous tip of the spine, and then along the iliac crest both inside and outside of the anterior superior spine the periosteum is loosened and stripped down, leaving the iliac crest bare. This denuding generally extends as far down as the anterior inferior spine. The leg is then hyperextended, when all the tissues slip away from the ilium, leaving a large space with often a setting down of from one to two inches in the origin of the muscle. The wound is closed, and the patient put up in a hyperextended plaster spica reaching well on to the thorax, and kept recumbent for six weeks.

SCOLIOSIS

Probably the most troublesome deformity in connection with infantile paralysis is lateral curvature of the spine, and its treatment has been very imperfectly formulated in literature, so that the writer is obliged to rely largely on his personal experience. The scoliosis may be evident while the child is still lying in bed, and of all the deformities is probably the one most frequently overlooked. Naturally the conditions of unilateral muscular paralysis which caused it in the first place

FIG. 61.—Severe left dorso lumbar scoliosis from infantile paralysis.

are going to persist in a measure, and it is not likely to recover or to improve spontaneously. It is due to a weakening of the muscles on one side of the body, and once weak they are likely to remain so for a long time if not permanently, in contrast with those of the other side.

To attempt to cure the deformity by exercise seems irrational, because the basis of the condition lies in a weakness of the muscles of one side, and although it may be very well to attempt to strengthen these muscles by exercise and is undoubtedly

proper, it would be a good while before they recovered power sufficiently to hold the spine straight against an oblique superincumbent weight. In the opinion of the writer it is definitely desirable in every case of lateral curvature due to infantile paralysis to support the spine as early as the deformity is discovered, even before the children are able to walk. Bone is an

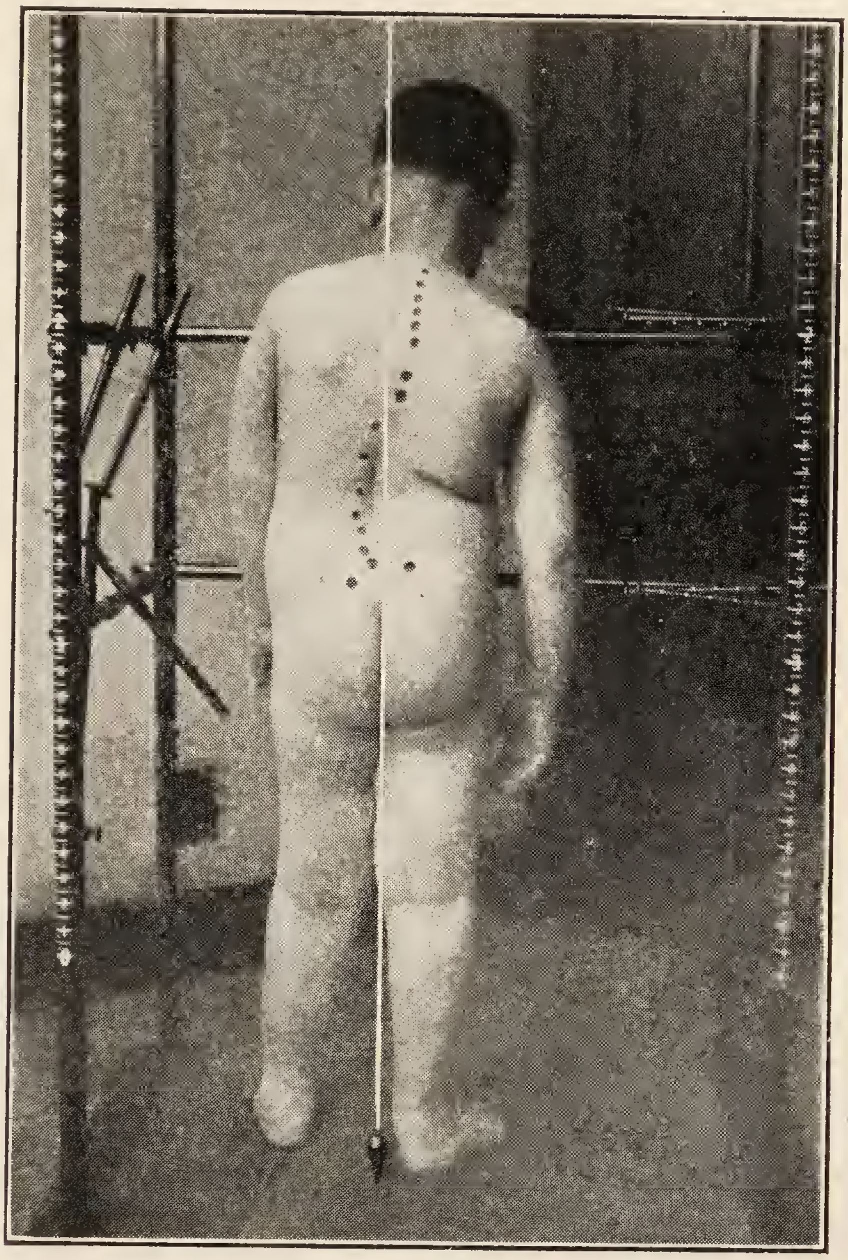

FIG. 62.—Scoliosis from infantile paralysis probably not associated with shortening in either leg as the gluteal folds are level although the posterior iliac spines are marked as uneven.

adaptive structure and grows in the line of least resistance, and to allow a growing child to sit, lie or stand in an habitually distorted position is to bid for permanent bony deformity. This has been established experimentally by Wullstein[1] and Arndt.[2] Moreover, the stretching of affected mucles by the

[1] Wullstein: "Zeitsch. f. Orth. Chir.," X, 2.
[2] Arndt: "Archiv f. Orth. Chir.," i, I, p. 2.

deformity is a menace to their improvement or recovery, and early cases are often cured by efficient support.

In the early stages the use of a canvas corset reinforced by steels is desirable, even in small children, to prevent the distorted position of the spine. This is a mild remedy, and improves the sitting position and in certain early cases cures the

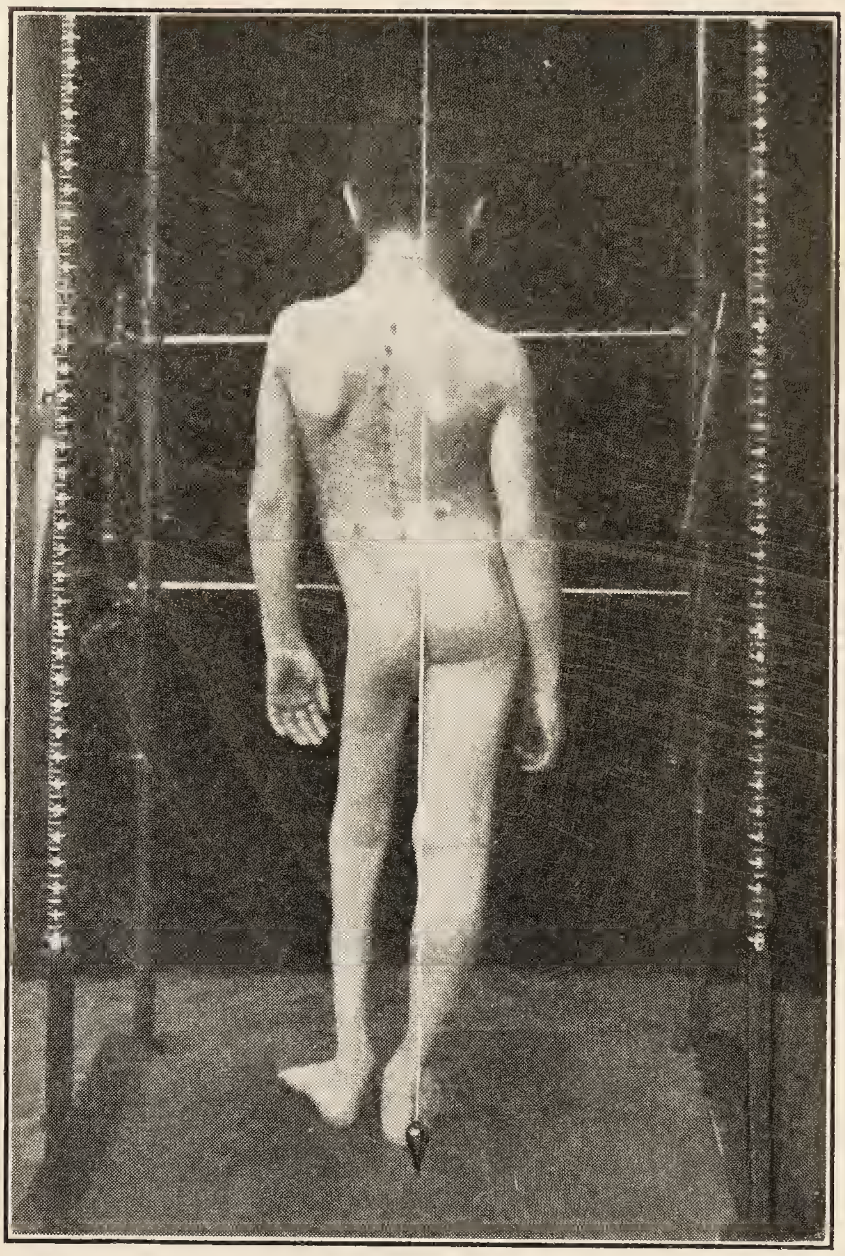

FIG. 63.—Scoliosis from infantile paralysis associated with shortening of the left leg.

deformity. Later on, when the deformity has become fixed, in the writer's opinion there is no alternative but to use mild forcible correction. The patient, with the knees flexed, lies face downward on a frame, on which run lengthwise two webbing straps (Figs. 68 and 69). By means of straps placed as shown in the illustration a lateral and unrotating force is exerted at the side of the curve, and a plaster-of-Paris jacket is then

applied.[1] When the plaster has hardened, a large window is cut out over the concave side of the curve and pressure exerted on the convex side and on the part rotated backward either by pads or by a strap known as the Cook strap,[2] which pulls the distorted portion of the prominent part of the spine toward the other side and forward. It is surprising what changes can be produced in cases of lateral curvature due to infantile paralysis

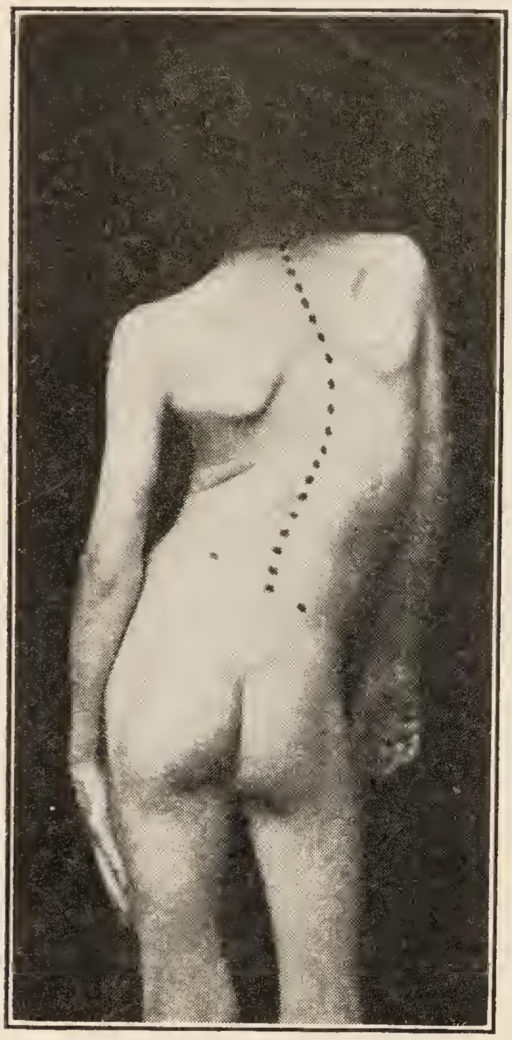

Fig. 64.—Scoliosis from infantile paralysis before treatment. (See Figs. 66 and 67.)

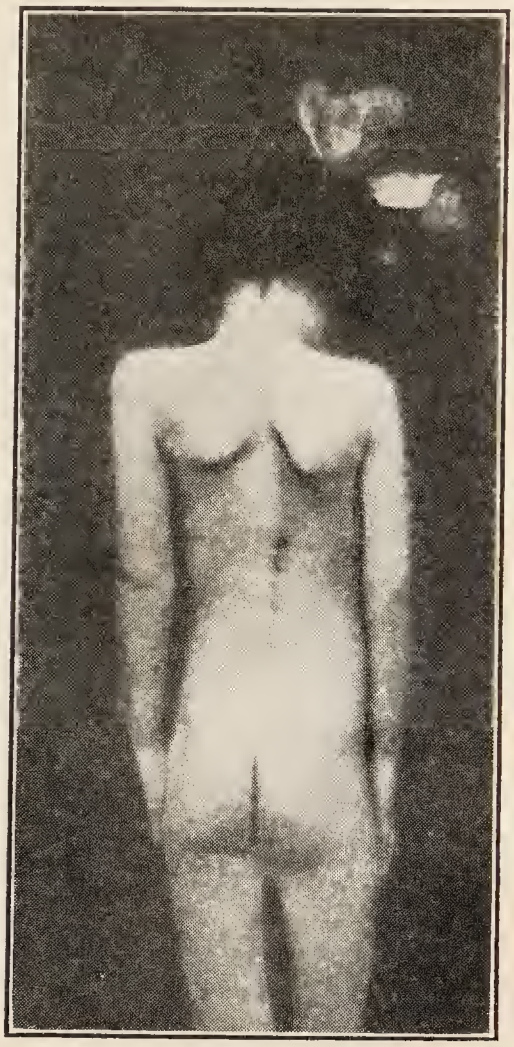

Fig. 65.—Scoliosis from infantile paralysis after six months' treatment by forcible plaster jackets (same case as Fig. 64; *x*-rays are shown in Figs. 66 and 67).

by this method.[3] Following this a removable leather or plaster jacket may be worn.

The deformity of lateral curvature in infantile paralysis when untreated reaches a very severe and highly troubling

[1] Lovett: "Lateral Curvature of the Spine and Round Shoulders," 3d edition, Philadelphia, 1916.

[2] Ansel G. Cook: "The Question of Balance," "Trans. Conn. Med. Soc.," 1913, p. 113.

[3] Lovett: "Bulletin," Department of Surgery, Harvard Medical School, May 20, 1915.

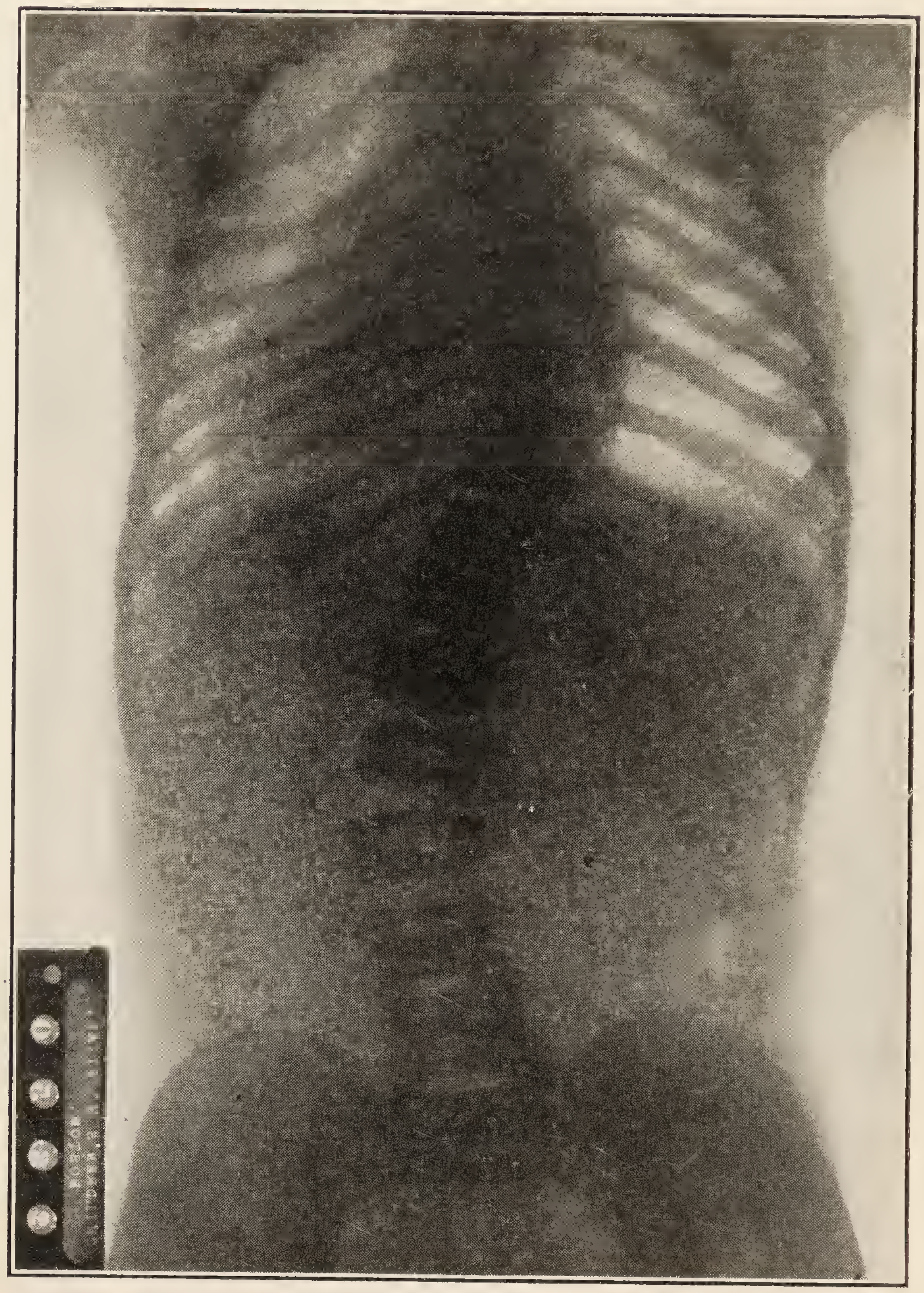

FIG. 66.—*X*-ray of patient shown in Fig. 64. Before treatment.

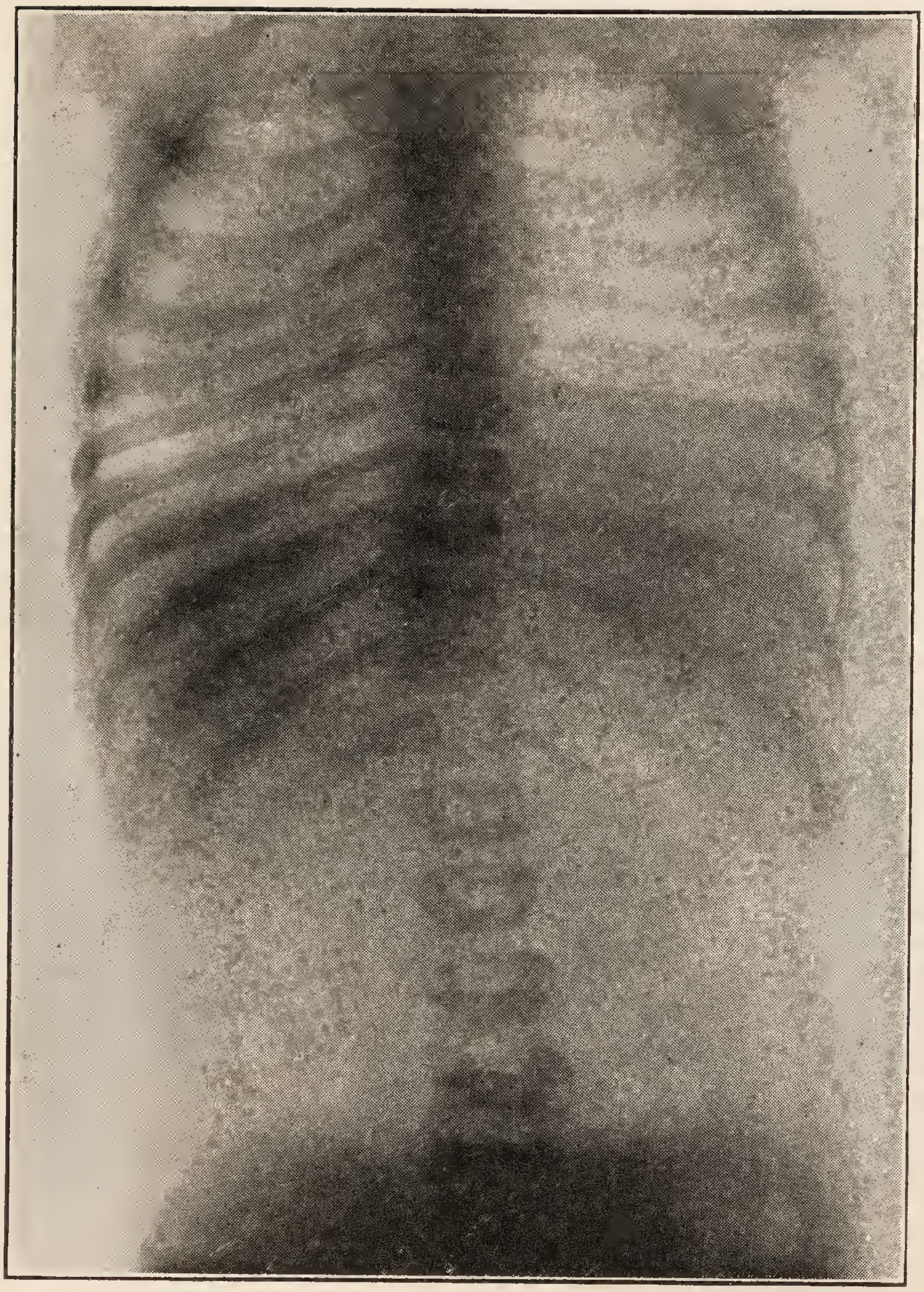

Fig. 67.—*X*-ray of patient shown in Fig. 65 after six months' treatment by forcible jackets.

degree, so that it seems useless to wait for this to occur. It is better to attack the deformity vigorously and on sound mechanical principles. It is probable that in most moderate and severe cases apparatus will have to be worn throughout early life and perhaps permanently, and this may consist of braces, corsets or jackets of plaster, leather or celluloid, but most cases will first require forcible correction as described above.

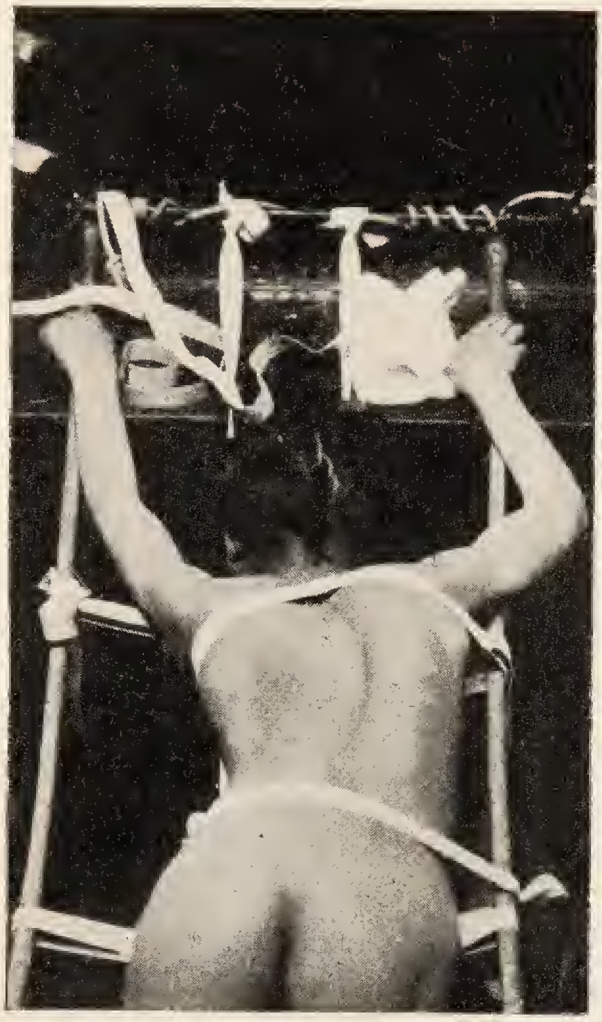

FIG. 68.—Patient with right dorsal curve lying in frame preparatory to application of plaster jacket.

FIG. 69.—Same as Fig. 68 showing effect of corrective strap over right thorax.

DEFORMITY OF THE UPPER EXTREMITIES

These deformities may occur, but are largely the effects of gravity and vary in type. There is one contraction of the shoulder which is of considerable practical importance, and that is a limitation of the abduction and backward motion of the shoulder-joint, which frequently occurs in connection with paralysis of the shoulder. This is a handicap to successful treatment by muscle training, and can always in the milder cases be removed by stretching.

In the other joints there is no fixed type of deformity, and when it occurs it is generally the result of disturbed muscular balance and the force of gravity, the latter being especially exemplified in deformities of the wrist occurring in paralysis of the arm, where the hand may fall to the ulnar side of the arm or into extreme hyperextension, and perhaps become contracted in these positions. (Fig. 39.)

CHAPTER V

TREATMENT

OPERATIVE—OPERATIONS TO IMPROVE FUNCTION—TENDON TRANSPLANTATION—NERVE TRANSPLANTATION—OPERATIONS TO IMPROVE STABILITY—ARTHRODESIS—SUBSTITUTES FOR ARTHRODESIS OF THE ANKLE—SILK LIGAMENTS—TENODESIS —ASTRAGALECTOMY—TENDON SHORTENING—SUMMARY OF OPERATIVE MEASURES

Aside from the operations intended for the relief of fixed deformities which have been described, there are most important operations which have for their aim the improvement of function. These operations again may be subdivided into two classes: (1) those intended to improve existing muscular function, and (2) those intended to secure stability. In regard to both of these classes of operations it should again be expressly stated that they are not to be done within two or three years of the acute attack, and that on the whole they are better suited to older than to younger cases. Cases under five are hardly suitable material for any of these proceedings, because the parts are at that time small, a great deal of growth is to occur, and post-operative distortion is much more likely to take place than when older cases are operated on. There is no definite rule to be laid down in this matter but on the whole the class of operations to be described is more satisfactory when performed at or after middle childhood.

I. OPERATIONS INTENDED TO IMPROVE EXISTING MUSCULAR FUNCTION[1]

Tendon Transplantation.—This operation is of much importance, and under proper conditions is one of the most brilliant operative proceedings in orthopedic surgery. Although the transposition of tendons was performed as early as 1770 by Nissa[1] in a traumatic case, and at various subsequent times

[1] Nissa: "Gaz. Salut," 1770, 2.
Vulpius: "Sehnenueberpflanzung," Leipzig, 1902.

tendon anastomosis was performed for similar conditions, it was first done in infantile paralysis by Nicoladonai, in 1880.[1] After its first description and after many modifications and much question as to its usefulness, the operation has reached a stable position where it is recognized as a useful, safe and brilliant operation if done under proper restrictions.

In theory it consists in the substitution of a healthy, non-paralyzed muscle for one which has lost power. For example, if the anterior tibial muscle is paralyzed, the foot falls into a position of valgus and eversion, and when dorsal flexion is attempted the foot is flexed in a position of abduction and eversion, the anterior tibial not holding it over to the inner side of the leg in this motion. A serious and disabling deformity thus starts, which in a growing child is likely to get steadily worse. Retention of such a foot in a brace is difficult to accomplish mechanically, and means that a brace must always be worn, whereas if the peroneal muscles are left unparalyzed one of these may easily be substituted for the anterior tibial. It makes no difference to a muscle where it is inserted for it pays but little attention to a change of its distal end. It is therefore possible to rebalance a foot by this proceeding. Every case represents a separate anatomical problem, and there are certain general rules regarding the operation which it is well to bear in mind.[2] It must be remembered however that a tendon transplantation cannot be done unless there are at hand fairly normal muscles to transplant. The question does not arise in a wholly paralyzed region.

Insertion.—Originally the transplanted tendon was sewed to the tendon for which it was to be substituted,[3] but this method has been on the whole less satisfactory than the insertion into the periosteum, as advocated by Lange,[4] and the periosteal insertion now prevails. Another distinct modification of the operation has been brought about by the discovery that when

[1] Nicoladonai: "Wien Med. Presse," 1881, s. 46.
[2] Bucceri: "Arch. di Ortop.," 1909, 2.
Kirschmer: "Beitr. zur Klin. Chir.," 65, p. 472.
[3] Vulpius: "Behand d. Spin. Kinderlahmung," Leipzig, 1910.
[4] Lange: "Ergeb. d. Chir. u Orth.," Bd. II, Berlin, 1911.
Lange: "Zeitsch. f. Orth. Chir.," Bd. XVII, p. 266 and Bd. XXX.

a muscle is too short to reach to its destined insertion it can be prolonged by silk, which is inserted in place of the tendon as a prolongation of it, and this silk becomes surrounded by fibrous tissue, making a perfectly good tendon. This technique as worked out by Lange[1] has increased greatly the efficiency and applicability of the operation, and it is now extensively used.

In transplanting a tendon, therefore, there are three methods which may be pursued: (1) The tendon may be sewed into another tendon, as advocated by Vulpius;[2] (2) the tendon itself may be sewed into a slit in the periosteum; or (3) the tendon may be prolonged by silk and the distal end of the silk sewed into periosteum, or passed through a hole drilled in the bone. In a questionnaire[3] addressed to the members of the American Orthopedic Association in 1910, twenty-eight used periosteal implantation, five used tendon to tendon suture, and five used both methods.

Fig. 70.—Silk extension of tendon.

In the writer's experience the following general considerations are of great importance in securing satisfactory results after tendon transplantation:

1. Operative cases should be selected with care, and only those chosen in which it is perfectly clear that improvement is to be expected from the operation.[4] It is of doubtful utility to substitute such a muscle as one of the peronii for the gastrocnemius, because it cannot possibly hypertrophy to the extent of supporting the body-weight, and in general it is not wise to change flexors for extensors, as well coördinated function as a rule does not follow such operations.

2. Existing fixed deformity must be removed before tendon transplantation.

[1] Lange: "Weiter Erfahrungen über Seidene Sehnen." "Munch. Med. Wchsft.," No. 1, 1902. "Zeitsch. f. Orth. Chir.," XXIX. "Zeitsch. f. ärtz Fortbildung," 1905, No. 22.

[2] Vulpius: "Deutsch. Med. Wchsft.," 1912, No. 36.

[3] Lovett: "The Treatment of Paralytic Deformity," Int. Med. Congress, Budapest, "Boston Med. and Surg. Jour.," April 14, 1910.

[4] Robert Jones: "Brit. Med. Jour.," 1911, p. 1520; "Clin. Jour.," London, May 13, 1914.

3. Tendons should be inserted into periosteum either by being sewed there themselves or by means of silk extension. Tendons transferred should be passed subcutaneously, and it is essential that the transferred tendon should approach its insertion in the line of the tendon for which it is substituted. The passage of the tendon in the sheath of the replaced tendon as advised by Biesalski[1] has not been found necessary by the author.

4. Transferred tendons should be attached with moderate tightness so that when the limb is in the over-corrected position there should be moderate tension on the transferred tendon. From our best knowledge at present the period of fixation in the over-corrected position should be at least three months, after which a removable fixation plaster or supporting brace should be worn until a year after operation to hold the member somewhat overcorrected to prevent strain from coming on the transferred tendons. From the time that the fixation plaster is removed, massage and muscle training of the transferred muscles should be followed out.

5. There are two dangers to be remembered in the after results: (1) insufficient correction, and (2) over-correction, the former being the more frequent. At the same time a very bad valgus may result from the taking away of the anterior tibial from the inner side of the foot and transferring it into the outer border. In this operation objectionable over-correction is more likely to result than in any other operation, although the transfer of both peroneals to the inner side of the foot may result in an objectionable varus.

6. In the matter of technique, it must be evident that where masses of silk are to be left in the subcutaneous tissue after a long dissecting operation the strictest asepsis is required. Fingers should never be put into the wound, the silk should be handled by forceps, and in every respect the most rigid asepsis should be maintained from the beginning of the operation until the end. Under these conditions drainage is not necessary. The operations are performed with the use of the Esmarch bandage.

[1] "Deutsch. Med. Wchsft.," 1910, No. 35.

Preparation of Silk.—As to the preparation of silk, this has gone through many modifications, at one time silk prepared in paraffin being almost exclusively used. After a trial of all methods the writer has settled down to a perfectly simple method, which has given more satisfaction than any other one used, by its simplicity, its efficiency and its failure to irritate the tissues. Common twisted silk, sizes 16 and 18, is used for silk extensions, and is boiled for half an hour in 1:1000 solution of corrosive sublimate. It is then taken from this and boiled with the instruments immediately before the operation, and used in a sterile towel. This preparation has given rise to less irritation from the silk than any other method including paraffin silk, plain boiled silk, and silk boiled in oxycyanide of mercury.

Operative Plan.—There is no definite rule to be laid down as to which are and which are not available operations. In the earlier operations there was a tendency toward great complexity, splitting of tendons, doing many things at once and a generally intricate plan. The later operative tendency among the most experienced surgeons is toward simpler operations, attempting to do fewer things at a time, and to do things that are obviously of anatomical benefit and which are mechanically sound. The most frequently performed and the most available operations are the following:

Foot.—In a *dropped foot* the anterior tibial and larger extensors may be paralyzed, but the extensor of the great toe may be active and contribute toward the dorsal flexion of the foot by its action. It can only do this, however, after it has hyperextended the toe. This muscle will work to better advantage if it is given an insertion into the inner side of the tarsus, preferably anterior to the scaphoid bone. Although it is not a powerful muscle it will aid in preserving the balance of the foot, and at times helps the efficiency of the foot by increasing the power of dorsal flexion.

In cases of *varus* where the peroneal muscles are paralyzed, the anterior tibial muscle should be cut off just above its insertion, freed to the junction of the lower and middle third of the leg, and then passed down subcutaneously to a point a

little to the outside of the middle of the dorsum of the foot and given a periosteal insertion at about the level of the medio-tarsal joint. It is not wise to make this insertion much out-

FIG. 71.—Tendon transplantation extensor of great toe inserted with tarsus.

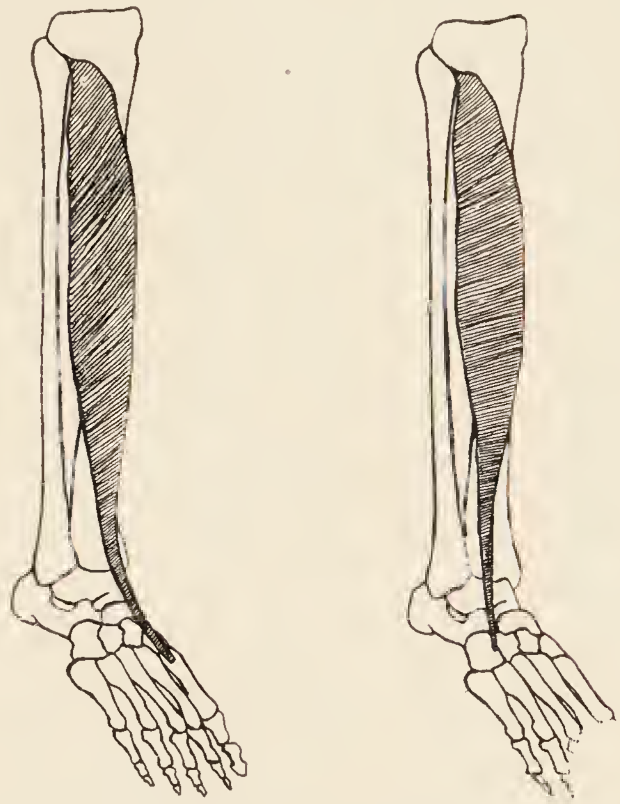

FIG. 72.—Tendon transplantation anterior tibial to outer side of foot.

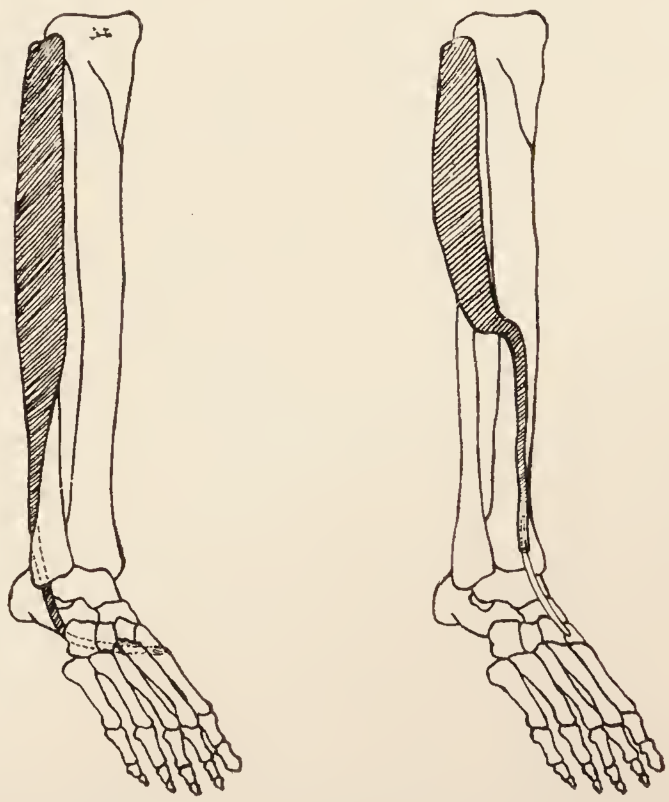

FIG. 73.—Tendon transplantation peroneus longus to inner side of foot.

side of the third metatarsal bone, for the reason that the foot may become overbalanced and a serious valgus result.

In cases of *talipes valgus* resulting from paralysis of the an-

terior tibial, if the peroneals are good, one of the peroneals may be transplanted to support the inner side of the foot, and this is one of the most brilliant of the tendon transplantations. It is dangerous to transplant both peroneals, and if one is used it must not be put too far in on the foot. It does not matter which is taken, but the peroneus longus is generally used. A long incision is made, and one of the peroneals divided near its insertion. The muscle then is cleared nearly to the middle of the leg and then subcutaneously passed directly inward transversely to an opening made over the crest of the tibia. It is pulled out through this, and from this passed down to the inner side of the foot, where it is inserted in the usual way. In this operation a silk extension of the tendon is necessary, as the tendon will not reach to the new insertion. It is better to sew up the empty sheath of the transferred tendon, as it has happened in cases of the author's that what appears to be an active tendon has developed in such sheaths. In one case both peronei were transferred to the inner side of the foot. The sheath was carefully sewed up, and some years afterward a functioning tendon was found at the site of the peroneal muscles. The object of passing the tendon transversely across at the middle of the leg is to bring the transferred tendon down to its insertion in the line of the tendon which it is to replace. A tenotomy of the tendo Achillis in connection with this operation should be performed with great reserve because a calcaneus frequently follows such a procedure. When absolutely necessary an open plastic tenotomy should be done to prevent indefinite lengthening of the tendo Achillis.

When the *tibialis posticus muscle* alone is paralyzed, a valgus position results, and for the paralyzed muscle may be substituted the flexor hallucis or the tendon of the peroneus longus brought around under the tendo achillis and sewed to the periosteum at the inner side of the foot.

Talipes calcaneus is a condition not in the writer's opinion likely to be benefited by muscle transplantation. The peronei or posterior tibial may be substituted for the gastrocnemius but they have in the writer's experience never been strong enough for good function and such operations have uniformly been unsatisfactory.

Hamstring Transplantation.—This operation is frequently performed at the knee, one or two hamstring muscles being carried forward and inserted by silk extension into the tubercle of the tibia. At least one good hamstring must be left in place at the back of the knee to serve as a flexor of the knee and the operation should not be performed unless the gastrocnemius is good, because that also is a knee flexor. Although the operation is often successful in improving quadriceps function, it occasionally fails to secure active extension movement although the knee may be stable for weight bearing and is most likely to be successful if the quadriceps possesses some power, being not wholly paralyzed. Prolonged fixation is required before weight is allowed to come upon the knee.

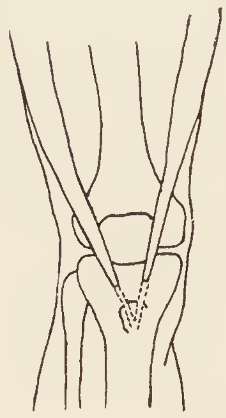

Fig. 74.—Tendon transplantation, hamstrings forward.

The theoretical difficulty about the ultimate result of the operation is that flexors never work altogether well as extensors, and although in time the patient may be trained to extend the knee ultimate function is sometimes unsatisfactory.

At the *hip*, satisfactory tendon transplantations are rare. Lange has substituted the vastus externus for the paralyzed gluteus medius and minimus. The upper attachment of the vastus is detached from the trochanter major, and by a series of silk attachments sewed to the crest of the ilium, aiding the abduction power to the leg.[1]

The sartorius was substituted[2] for the quadriceps muscle in earlier operations, but it is a small muscle and is not likely to prove a satisfactory substitute.

Other Transplantations.—In the *arm*, at the shoulder the trapezius has been frequently transplanted to substitute for the deltoid,[3] but in nearly all cases this results in failure, and

[1] Lange: "Am. Jour. of Orth. Surg.," August, 1910, p. 19.
[2] Goldthwait: "Boston Med. and Surg. Jour.," 1897, No. 20.
[3] Bradford: "Am. Jour. of Orth. Surg.," VIII, p. 21.
Killiani: "Annals of Surgery," January, 1910.
Katzenstein: "Berlin Kl. Wchsft.," Dec. 6, 1909.
Lewis: "Jour. A. M. A.," Dec. 14, 1910.
Spitzy: Zeitsch. f. Orth. Chir., xxx, Beilage Heft, p. 221.

although occasional cases succeed, the operation is on the whole unsatisfactory and not to be recommended. There is, however, an operation that is fairly successful in substituting for the deltoid the pectoralis major muscle. A long incision is made comprising the sternal and half of the clavicular origin of the muscle and reaching over the shoulder to the spine of the scapula. The sternal and clavicular parts are then detached from the chest as high up as is safe without impairing the nerve supply, and this portion of the muscle is then slung over the shoulder and sewed into the spine of the scapula subperiosteally (Legg's technique). The arm is then done up in a position of abduction on a level with the shoulder, and retained in this position for several months. Excellent results have been in many cases obtained from this method (Hildebrand, Sachs, Samter, Lange, Legg).

In the arm, tendon transplantation has not on the whole been nearly as satisfactory as in the leg. When need for tendon transplantation in the arm does arise it is generally perfectly clear, but there is no one type of operation in general use, and each case must be worked out on general anatomical principles.

In the leg in certain cases it is desirable to combine tendon transplantation with tendon fixation, astragalectomy or silk ligaments, which serve as reinforcements. Tendon transplantation is applicable to both adults and children at or after middle childhood.

After-treatment.—The after-treatment of muscle transplantation has been already spoken of, and in this place it is only necessary to repeat the fact that prolonged after-treatment is one of the essentials to success. Fixation should be persisted in for from three to six months, according to the weight to be borne on the member when use is resumed, and at least six months more in a rigid plaster or metal splint. After a few months, massage and muscle training should be begun, and should be continued until the limb is ready for unprotected use, which will not be until a year after the operation.

Of course, in many cases massage and muscle training are not available, but a better result as a rule is obtained when they are used. When weight is borne, a year from the time of operation,

the mechanical conditions should be made favorable. For instance, when the foot was originally in valgus it is wise when weight is first borne to tip it to the outer side by raising the inner side of the heel or of both heel and sole, to take the strain off of the inside, and *vice versa* for the deformity of varus.

In the opinion of the writer it is not sound surgery when the thigh is paralyzed in such a way that weight cannot be borne upon the leg in walking to do tendon transplantation or other radical operations in the ankle except to correct deformity. Muscle transplantation is an operation requiring a long disuse of the leg, and when the upper leg is useless for walking purposes there is no need of attempting to give greater power to the foot, because it could not be used for unaided walking on account of the condition in the upper leg, and some form of brace would be necessary anyway.

NERVE TRANSPLANTATION

The anastomosis or transplantation of nerves whereby an unaffected nerve is attached to one whose function has disappeared is a proceeding which is physiologically sound and which can be demonstrated experimentally in animals as efficient. But in the case of patients although successes are reported, on the whole the operation has not as yet been widely performed. Spitzy and Stoeffel have perhaps contributed more to the present knowledge and technique than have the various others whose names have been connected with the operation (Bethe, Hackenbruch, Kilvington, Kennedy, Tubby, Zeiss, Bardenhauer).

The sound peripheral nerve may be transplanted into the affected one either peripherally or distally, the insertion may be central or peripheral, the whole or part of the nerve may be used. Spitzy advises that the operation be performed before there is too great degeneration of the affected nerve ends in the muscle.

"If the life of the muscle deteriorates for months, the nerve plastic should then be undertaken, for a spontaneous regeneration must show

itself in the course of the first six months either by a little twitching in the muscle or by an increase or at least stationary condition of the quantity and quality of the electrical irritability."

If successful, power may be expected to begin to return from the third week onward, the return of voluntary action generally preceding that of electrical.

The results claimed by Spitzy in 1911[1] were not particularly encouraging because he of all operators had probably the largest experience in the experimental and clinical development of nerve transplantation. His results were in sixty-one operations 30 per cent. good, 40 per cent. not entirely satisfactory, and 30 per cent. bad. In the hands of a less skillful person the percentage of success would probably be far lower. Again the necessity of early performance is in a way an obstacle to the general acceptance of the operation because it has been recently shown[2] that the possibility of the late return of power is greater than formerly supposed and this is opposed to operative procedures until this possibility is gone.

Routine examples of nerve plastics are the following: In paralysis of the hip a branch of the obturator nerve is transplanted into the anterior crural. For relief of paralysis of the quadriceps the paralyzed crural nerve is transplanted into the sciatic. In another case a branch of the sound crural nerve was carried through a tunnel in the symphysis pubis and transplanted into the paralyzed nerve on the other side of the body (Borgle and Maragliano). The peroneal nerve may be used to innervate the tibial and the tibial nerve, the peroneal, etc. The literature of the subject of nerve transplantation is quoted rather fully in order that one may consult the original sources from which the preceding facts have been collected.[3]

[1] Spitzy: "Handbuch d. Kinderheilk," Lange and Spitzy, Leipzig, 1910, p. 310. "Jahrbuch für Orth. Chir.," 1911, Berlin, p. 45.

[2] Lovett and Martin: "Jour. A. M. A.," Mar. 4, 1916.

[3] Osgood: "Review," "Boston Med. and Surg. Jour.," June 30, 1910.
Duroux: "Lyon Chir," December, 1912.
Zeiss: "Boston Med. and Surg. Jour.," May 11, 1911.
Stoeffel: "Munch Med. Wchsft.," 1910, 5.
Spitzy: "Zeitsch. f. Orth. Chir.," Bd. xiii.
Bardenhauer: "Arch. f. Klin. Chir.," Bd. 89, Hft. 4.

Kilvington: "Brit. Med. Jour.," April, 1907.
Vernicchi: "Arch. di. Ortop.," 1910, xxvii, p. 337. "Ref. Zentblt. f. Orth. Chir.," xxvii, 546.

Neurotization of Muscles.—It has been shown experimentally by Erlacher[1] and Steindler,[2] if a muscle is artificially paralyzed by nerve section and the peripheral end of a healthy nerve is implanted into the paralyzed muscle that in a few weeks electrical nerve impulses may be sent down the transplanted nerve and cause a contraction of the muscle in which it is implanted. The method may later be applicable in infantile paralysis but at present the method is wholly in the experimental stage and is not ready for clinical application.

II. OPERATIONS TO SECURE BETTER STABILITY

The operation of muscle transplantation aims at giving better function in the affected member by substitution of the tendon of a healthy muscle for that of a paralyzed one. In many cases there are no active muscles to transplant, all the muscles of the region being paralyzed. At the ankle, for instance, there is often a flail-joint, which is unstable in walking and which does not clear the ground on account of the toe-drop when the foot is off of the ground. Under these conditions a stable joint, especially an ankle which is checked from dropping, is more useful than a flail-joint, and numerous operations have been proposed for the stiffening of the ankle and other joints, thus securing greater stability.

Arthrodesis.—An artificial ankylosis thus named produced by the removal of the articular cartilage has been in extensive use, particularly at the ankle-joint. It was named by Albert who was the first to operate on a series of cases at the ankle-joint, which he reported in 1882. With the better development of the operative side of orthopedic surgery the operation of arthrodesis at the ankle is less often performed than was formerly the case because better functional results are to be obtained by other operations. The joint is opened, preferably by an anterior incision, the cartilage removed by a chisel or

[1] "Am. Jour. of Orth. Surg.," 1915, vol. xiii, p. 22.
[2] "Am. Jour. of Orth. Surg.," 1915, vol. xiii, p. 33.

osteotome from the top of the astragalus and the lower surface of the tibia and the foot being placed carefully at a right angle to the leg with no inversion or eversion, a plaster is applied and the ankle-joint is fixed for a period of some three months at least, in order to secure firm ankylosis. Many operators also stiffen the mediotarsal joint by removing the cartilage from that also to prevent a drop of the forefoot which often happens and if one performs arthrodesis of the ankle it is desirable to stiffen both joints.

There are definite objections to the operation.[1] First, it causes a stiff ankle which is a handicap in walking and causes some limp because it does not allow dorsal flexion of the foot. And, second, if young children are operated on, in a certain number of cases the result will be a distorted foot, generally twisted into the position of varus. A third objection often made is that firm ankylosis may not occur at the operated joint.

Although it would seem that a sufficiently destructive removal of joint surfaces would surely result in ankylosis the fact remains that skillful and experienced surgeons will occasionally fail to secure a stiff joint. The greatest safety lies in waiting until the bones are sufficiently ossified to allow bony surfaces to be exposed and then after a sufficiently radical operation to place in accurate apposition raw bony surfaces.

In the writer's opinion arthrodesis of the ankle is an operation yielding at the best an imperfect functional result and although often desirable in adults it seems dangerous in young children and less desirable in older children than the measures to be described.

Arthrodesis of the *knee* is not an operation to be lightly undertaken, because in children to shave off enough cartilage to secure ankylosis may change or injure the epiphyseal lines and very seriously interfere with the growth of the leg which takes place largely at the knee epiphyses. At best, even in adults, it furnishes a stiff knee which cannot be bent, and a stiff knee is awkward and unhandy, so that most people prefer to

[1]Laau Nederlandsch Tijd. v. Geneeskunde II., No. 16, p. 1347.

wear a brace. This operation at the knee, therefore, in the opinion of the writer should not be encouraged.

Arthrodesis of the *hip* is not a very satisfactory operation, because often one fails to secure bony ankylosis. When the operation is performed nothing short of a complete denuding of the head of the femur and of the acetabulum is likely to serve. The Hoffa-Lorenz incision is used, the capsule opened and the cartilage thoroughly removed from both surfaces. The leg is then put up in a plaster-of-Paris spica in slight abduction.

In the *arm*, arthrodesis of the *shoulder* is a useful operation where there is complete paralysis of the shoulder and where no muscle transplantation is possible. The arthrodesis is done through an anterior incision and the arm fixed in a position of slight abduction from the side. If ankylosis occurs very useful function will result, because by scapular movements it is possible to raise the arm to a horizontal position. It is probable that, in addition to the arthrodesis, fastening the humerus to the acromion by heavy silk strands makes the operation more likely to succeed.

Arthrodesis of the *elbow* to secure a right-angled joint in cases of complete paralysis of the arm would be perfectly useful were it not that in these cases as a rule the hand is also paralyzed, and a right-angled elbow with a dangling hand is not a very useful arm. It is an admirable operation when conditions are favorable.

Substitutes for Arthrodesis of the Ankle.—*Other operations* as additions to, modifications of, or substitutes for arthrodesis are the following:

1. *Hoffa.*[1]—All the extensors *en masse* were gathered up with a hook and shortened by means of making a loop. Relapse followed as a rule from stretching.

2. *Vulpius*[2] (Fasciodesis).—The extensor tendons are sewed to the fascia over the skin. Later the operation was combined with arthrodesis. Alone it was unsuccessful.

3. *Cramer*[3] lays a periosteal flap over the anterior surface of the joint.

[1] Hoffa: "Orthop. Chir.," 5th edition, Stuttgart, 1905.
[2] Vulpius: "Zentralbl. f. Orth. Chir.," 1907, p. 97.
[3] Cramer: "Zentralbl. f. Orth. Chir.," 1910, p. 113.

4. *Codivilla*[1] performed an arthrodesis of the ankle-joint and then fastened a part of the tendo achillis to the dorsum of the foot and sutured the tendon of the peroneus brevis drawn from the sole of the foot to the bones of the leg and shortened the anterior tendons.

5. *Lexer*[2] drove a bone peg from the sole of the foot through the tarsus into the bottom of the tibia and Bade used an ivory peg in the same way. The bone peg is usually absorbed in about one year, after which motion generally returns.

6. *Jones.*[3]—In cases of paralytic equino-valgus where inversion of the ankle is not possible on account of contractions an arthrodesis is performed at the ankle. A wedge, three-fourths of the diameter of the bone, is removed from the tibia and the fibula is also divided. The foot is then put up in the position of eversion for two weeks when the bones where partly divided are fractured and the foot put up in proper relation to the leg.

7. *Jones.*[4]—In paralytic calcaneo-cavus an operation devised by Jones is performed in two stages. First, a narrow tarsal wedge with base upward is removed quite across the foot, the cavus corrected and the foot bandaged to the tibia in extreme dorsal flexion. After a month in this position an arthrodesis is done at the ankle and at the same time a wedge is removed from the astragulus. The foot is then fixed at a right angle.

8. *Transverse Section of the Foot.—Davis*[5] has described an operation for calcaneus and calcaneo-cavus deformity which, although complicated and somewhat difficult in its performance, is attended by excellent functional results. The technique is as follows:

"An incision is made on the outer side of the foot about two inches long, extending from the posterior edge of the external malleolus forward; it lies close to its tip. The long and short peroneal tendons then come into view and if it is desired to transplant them into the os calcis they are cut long and turned out of the way. If it is desired to preserve them

[1] "Zeitsch. f. Orth. Chir.," Bd. xii, p. 221.
[2] "Archiv f. Klin. Chir.," Bd. xcviii, Hft. 3.
[3] Robert Jones: "Report on Arthrodesis," xvi, Int. Cong. of Surg., September, 1909.
[4] Robert Jones: "Am. Jour. Orth. Surg.," April, 1908.
[5] "Am. Jour. Orth. Surg.," October, 1913, p. 240.

intact, they can be loosened from their sheaths and held aside. Through this incision, with a chisel and periosteal elevator, the soft structures are raised from the bones anteriorly and posteriorly. Then a transverse horizontal section of the bone is made in the line of the skin incision, but passing entirely through the tarsus from the junction of the os calcis and astragalus posteriorly and emerging on the anterior surface of the cuneiform bones. In making this bone section no attention is to be paid to the joints. It passes through the subastragaloid joint cutting off parts of the upper portion of the os calcis and lower portion of the astragalus; it may clip off a piece of the upper portion of the cuboid, the scaphoid and the upper portion of the cuneiform bones. These pieces may or may not be removed. As it is too difficult to loosen the foot sufficiently through this incision another about one inch long is made on the inner side of the foot below the internal malleolus and over the sustentaculum tali. The tendon of the tibialis posterior is exposed and loosened from its sheath and held out of the way. The soft parts having been loosened from the bones anteriorly and posteriorly the bone section is completed from the inner side. An effort is then to be made to push the foot back and the leg forward. If this cannot be done then with a chisel or other instrument the soft parts are loosened still more until the foot can be displaced as far backward as is desired. Any loose pieces of cartilage or bone that may be present in the incision can be removed. If desired, the peroneal tendons can now be implanted into the os calcis, the external incision being prolonged backward or a posterior incision added if necessary. To hold the foot in its new position chromic gut sutures may be passed from the tibia and fibula above to the tarsal bones below. The wounds are to be closed without drainage, and the foot put up in plaster of Paris. A wooden sole plate is to be incorporated with the plaster and it is to be placed in a position of slight varus and equinus. While the plaster is setting, the foot is to be pressed firmly back and the leg bones forward as much as possible. If desired, at the end of a week or so, a window may be cut in the plaster and the wound inspected, or the plaster and dressing may be entirely renewed and this left on until eight weeks have elapsed. The plaster cast is then removed and a simple ankle brace substituted to keep the foot from everting under pressure. This may be worn for a few months until bony consolidation is complete, to be followed by a suitable shoe."

9. *Biesalski*[1] makes a transverse incision over the dorsum of the foot, divides the extensor and tibial tendons higher up and turns them back and does an arthrodesis of the ankle-joint and mediotarsal joints. A hole is then bored in the tibia

[1] Biesalski: Lange's "Lehrbuch der Orthopädie," Jena, 1914, article "Nervenkrankheiten."

running longitudinally up and forward. The divided tendons are drawn through this hole and fastened to the fascia and periosteum of the tibia. Sometimes such strands also are passed from the insertion of the tendo achillis to the posterior surface of the tibia.

Fig. 75.—Fixation shoe for ankle for post-operative use.

10. *Silk ligaments.*
11. *Tenodesis.*
12. *Astragalectomy.*

The three latter, an account of their more general use, will receive more extended consideration.

SILK LIGAMENTS[1]

The use of silk to extend tendons and reinforce joints by forming artificial ligaments depends upon its property of becoming surrounded by fibrous tissue. This was brought to the notice of the profession by Lange[2] although the original use of silk ligaments was credited by him to Herz.[3]

The operation possesses the advantage, in cases of foot-drop, of allowing dorsal flexion but preventing foot-drop. The operation has in the writer's hands proved on the whole useful in properly selected cases and the following figures were collected from an analysis of cases. It has the advantage of not interfering with the muscles of the ankle-joint, so that if there is a return of power in partly paralyzed anterior muscles following the relief of their stretched position the power to dorsally flex the foot may return. The disadvantages of the operation are that the silk sometimes breaks probably because too few strands are, as a rule, used, that care is required in correcting the balance of the foot to one side or the other, and that knots in the silk if left below the level of the boot may chafe through. These defects are partly remediable but the operation at times, in spite of all precautions, fails. In the use of silk ligaments at the ankle three different techniques are used:

[1] Lovett: "Am. Jour. Orth. Surg.," January, 1915.

[2] Lange: "Münch. Med. Wchrft.," 1907, 17. "Zeitsch. f. Orth. Chir.," xvii, 266.

[3] Herz: "Münch. Med. Wchrft.," 1906, 51.

(*a*) **Periosteal Insertion.**—An incision is made over the crest of the tibia, the periosteum turned back and silk quilted up one side of the reflected periosteum and down the other, and four or more strands then carried down under the annular ligament by means of a long flat probe with a large eye to an incision made in the tarsus, where it is desired to attach the silk. Here it is again quilted into periosteum. The insertion may be at the inner or outer side of the foot or at both or at the middle, and all strands passed to the desired spot and fastened there.

(*b*) **The Open-bone Method.**—The tibia is cut down on, the periosteum turned back, and a bone drill with an eye driven through the tibia from side to side. Into the eye of the drill is then passed a loop of silkworm-gut, the two ends of which are drawn through the hole, while the loop remains on the other side and the drill is disengaged and the leader left in place. The point on the foot is then selected for the tarsal insertion and cut down on and drilled in the same way and by means of a leader of silkworm-gut silk is drawn through the tarsal hole in the bone. If the foot is large, two double strands of silk about No. 12 should pass through the hole, and eight strands would then be carried up to the tibia. If larger silk (No. 18) is used, fewer strands are needed than with No. 12. Strands may pass to both inner and outer sides of the foot from the same hole in the tibia if desirable for stability. From the tibial incision is then passed down the probe, the silk passed through the hole in the tarsus is then put through the eye, and passing under the annular ligament is brought out of the tibial incision. Half of the silk thus brought up is then passed through the loop of the silkworm-gut leader, which was left in the drill hole in the tibia, and drawn through, the foot is placed in the desired position and the silk tied, the knot being located at the outer side of the tibia between it and the fibula. In this way no knot is left for pressure in the foot from the boot.

(*c*) **Subcutaneous Bone Method.**—In this method a drill with an eye is driven directly through the skin without an incision at the desired location in the foot, and by means of a leader of silkworm-gut the silk is then carried through the drill hole. The tibia is then drilled in the same way without an

incision, and through the drill hole in the tibia, enlarged slightly if necessary, a stiff flat probe with an eye is passed down and out through one of the drill holes in the tarsus, the silk passed through it and drawn back and out of the upper hole. The same proceeding is repeated for the other drill hole in the tarsus. The silk strands are then drawn through the hole in the tibia by a leader, and the drill hole opening where the strands emerge is enlarged sufficiently to allow a deep knot to be tied.

Choice of Methods.—The preference of the writer is for the open-bone drill method. Periosteum is often thin and tears easily. It has been found in some cases that the silk not only tore out of the periosteum, but in other cases pulled away the periosteum from the bone in a long nipple-shaped process, and the analysis which follows shows that the proportion of good results from the bone operation is larger than that from the periosteal.

The open-bone operation seems better than the subcutaneous because it seems likely to stir up more periosteal activity at the site of the drill holes, which would result in the deposit at these places of bone from the stripped up and displaced periosteum.

In estimating the usefulness of the operation it is necessary to consider the really ultimate results, that is, the results a year or more after operation. It is often the case that six months after operation the result apparently is perfect, but after some months more, when all apparatus has been removed, the result proves to have been unsuccessful, and a relapse into the original condition occurs.

As personal impressions are likely to be misleading, and as the operation is not regarded with favor by many excellent operators, the attempt has been made to see what the results really were in 1914 in the cases operated on at the Children's Hospital, Boston, in the years 1907–1913 inclusive. The seventy-nine operations analyzed were performed by the different members of the staff, and represent the work of six operators. The conditions under which the operations were done were much the same for all, so far as operating conditions were concerned, but the technique varied among different operators.

Analysis of Results.—Of seventy-nine operations on sixty-eight patients, fifty-one were periosteal insertions and twenty bone, while in eight it was not stated whether the bone or periosteal method was used. Results were classified as successful when the desired result was obtained and the foot held at a right angle, partially successful when the condition was improved by operation but when there was some dropping of the foot. The term failure shows no perceptible improvement from the operation, but it is of interest to note that in no case was the condition made worse by it.

Of forty-four periosteal operations where the result could be verified:

30 per cent. (13 cases) were successful.
20 per cent. (9 cases) were partially successful.
50 per cent. (22 cases) were failures.

Of seventeen bone drill operations where the result could be verified:

70 per cent. (12 cases) were successful.
12 per cent. (2 cases) were partially successful.
17 per cent. (3 cases) were failures.

Where an external ligament has alone been required the fibula has been used instead of the tibia for its upper insertion, putting it through the fifth metatarsal or cuboid below. For an internal ligament the silk has been run from the tibia to the scaphoid or cuneiform.

In tying the knot the foot should be fully at a right angle with the leg, as in no case has the writer seen any over-correction from growth. It has been stated that while the leg grew the silk did not, and that deformity would come as a result. In no case in the series has there been any suggestion of this, nor has any evidence been seen of over-correction in any direction.

The cases are now kept recumbent for two or three weeks after operation, and are kept quiet for two months or so. They should wear a plaster for from four to six months and a supporting brace after that until a year from operation, and until a year has elapsed no unsupported weight should come on the silk.

It is not necessary to disturb the foot to look at the wound,

but the patient wears the plaster applied at operation for three or four months. In careless patients it is well to continue the plaster for a year. The time of fixation in the earlier cases was as a rule much less than this which probably accounts for the less satisfactory results in the earlier cases of the series.

The use of posterior ligaments at the ankle-joint to check dorsal flexion in cases of *calcaneus* has not proved satisfactory, nor is there any especial reason why it should, because in walking the whole weight of the foot must come upon the ligament, and such mechanical conditions are the worst possible for securing success. After trying the method in a number of cases the writer is of the opinion that it is of no value in calcaneus.

The use of internal articular silk ligaments to secure greater stability and to modify malposition in various joints has been described by Bartow and Plummer,[1] but the matter has not commended itself particularly to the writer because joint stiffness to a large extent must follow and in cases severe enough to require this operation it would seem better to perform an arthrodesis or other radical operation. The matter is, however, still *sub judice*, although some satisfactory results have been reported.

Silk ligaments are sometimes used in connection with tendon transplantation.

TENDON FIXATION OR TENODESIS

The conversion of the tendons of the muscles passing over the ankle-joint into ligaments has been described by Tilanus,[1] Codivilla,[2] Sangiori,[3] Reiner,[4] Jones,[5] and Gallie.[6] As the last report of Gallie comprises 150 operative results his technique rather than that of the earlier writers will be described.

The method consists in exposing and isolating the one or more of the paralyzed tendons whose support is desired. The tendon

[1] Tilanus: "Ned. Tijdschrift Voor Geneskunde," 1898, II, 23.

[2] "Jour. Am. Orth. Assn.," August, 1911, p. 65.

[3] "Revista de Ortopedia," 1901, No. 1.

[4] "Zeitsch. für Orth. Chir.," 1903, Hft. 2.

[5] "Lancet", May 30, 1914.

[6] Gallie: "Annals of Surgery," March, 1913, October, 1915. "Am. Jour. Orth. Surg.," January, 1916.

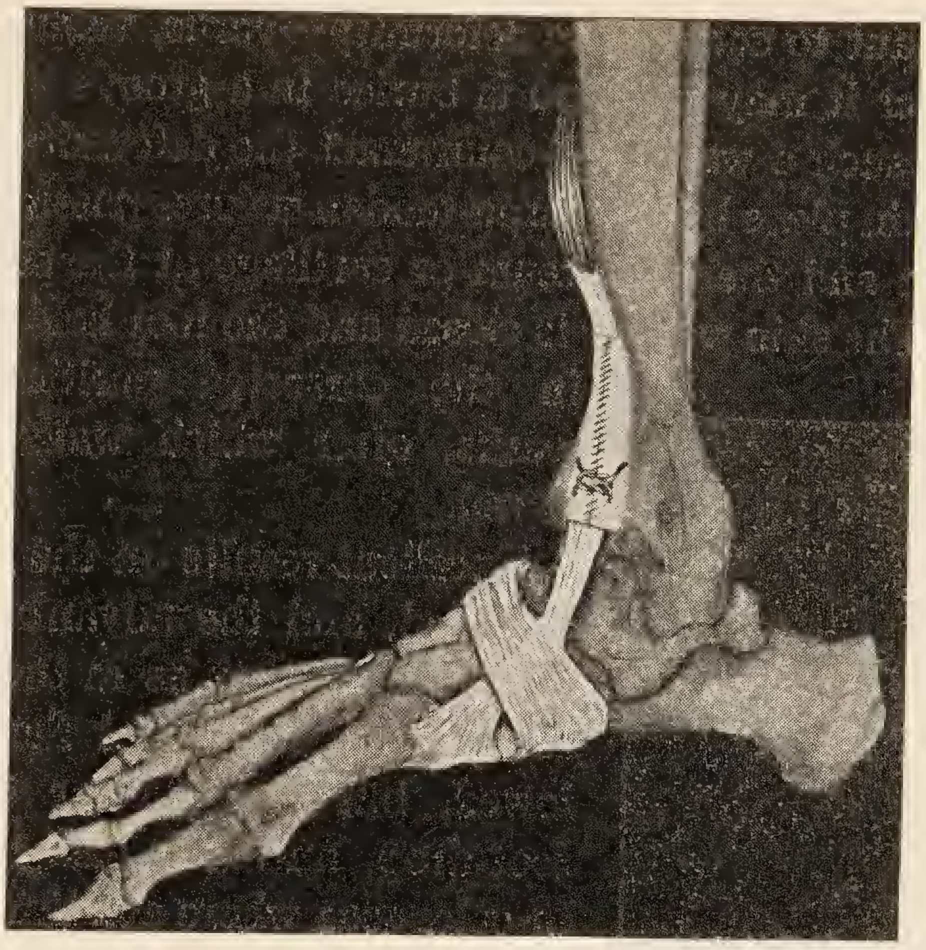

FIG. 76.—All the structures have been removed from the skeleton except the tibialis anticus muscle and tendon which has been buried in the tibia to prevent foot-drop. The stitches are shown. (*Gallie.*)

FIG. 77.—Tendon of peroneus longus has been fixed in anterior border of external malleolus and tendon of peroneus brevis is ready to be laid in trough prepared for it behind the malleolus. (*Gallie.*)

is drawn taut to correct the deformity—varus, valgus, equinus or whatever it may be—and is buried in a groove in the bone located in such a way as to counteract the deformity, scarified and sewed in place by kangaroo-tendon sutures passing through the tendon and the periosteum or cartilage at the sides of the groove. The skin wound is closed and the foot held by plaster in the corrected position for six weeks, after which walking is allowed.

Fig. 78.—The tendo achillis is fixed in the posterior surface of the tibia to prevent calcaneus and the peroneal tendons have been transplanted into the os calcis. (*Gallie.*)

Excellent results on the whole are reported, and the advantage of the operation is that as in the silk-ligament operation dorsal flexion is allowed, but not plantar flexion in foot-drop, and it is also to be used in calcaneus where silk ligaments are of no use. The disadvantage is that it permanently throws out of use muscles which might improve under the favorable conditions of balance brought about by the operation and that the anchored tendons at times slip or stretch. The operation may be used in addition to tendon transplantation just as in the case of silk ligaments to serve as a reinforcement.

ASTRAGALECTOMY[1]

One of the most useful operations in bad infantile paralysis of the leg has been devised by Whitman,[2] and is known as astragalectomy. It consists in the removal of the astragalus and the displacing of the foot backward on the tibia. The operation was originally devised for the treatment of cases of calcaneus in which the gastrocnemius was paralyzed and excessive dorsal flexion of the foot was present, but it has been applied to a larger

[1] "Annals of Surgery," February, 1908.
[2] "Am. Jour. Med. Sci.," November, 1902.

field of cases and is useful in cases of bad paralysis of the ankle where it is desired to secure greater stability of the foot, being in this matter preferable to arthrodesis, because in the modified operation as performed at the Children's Hospital, Boston, an ankylosed ankle is not aimed at, but one allowing a slight degree of motion. The operation is performed in this modified form by using the Kocher incision at the outer side of the ankle-joint, sweeping down below the external malleolus and running forward to the base of the fifth metatarsal. The peroneal tendons are either pulled aside or divided and sutured afterward, and the astragalus is exposed and enucleated with the foot dislocated inward. This may be done by dividing it at the neck, which makes the technique a little easier, or the astragalus may be removed intact. After the astragalus is removed it is desirable to loosen the internal lateral ligaments of the ankle from the inner surface of the tibia in order that displacement backward of the foot may be thoroughly effected, and this is done subperiosteally by means of an osteotome and a blunt dissector. When this has been loosened up sufficiently to allow posterior displacement of the foot on the leg, the foot is displaced backward so that the two malleoli grasp the front of the os calcis instead of the astragalus. The surfaces of the tibia and the top of the os calcis are not in this technique roughened, but left normal with the hope of securing slight motion. The external ligaments are united by sutures and the foot done up in a position of slight equinus, in plaster of Paris. Weight should not be borne for at least three months. Even then it may be wise to support the foot for a while longer by a brace if it does not seem wholly stable.

Occasional bad results come from astragalectomy in the way of distorted feet (varus, etc)., but on the whole with a proper technique the operation is satisfactory, and in many cases the result is excellent. Sometimes when there is slight muscular power left in one group of muscles it may be possible to add a muscle transplantation to an astragalectomy, the astragalectomy being done for the purpose of securing greater stability to the foot and the muscle transplantation to balance the foot to better advantage.

The original operation as described by Whitman is as follows:

"An Esmarch bandage having been applied, an incision is made from a point about one inch above the external malleolus midway between it and the tendo achillis, passing downward to the attachment of the tendo achillis, forward below the extremity of the malleolus and over the dorsum of the foot to the external surface of the head of the astragalus. The sheaths of the peronei tendons which are exposed at once, are opened throughout their entire length and the tendons, divided as far forward as the incision will permit, are thoroughly freed from all the attachments behind the malleolus and are drawn backward. One next divides the bands of the external lateral ligament, and the foot being somewhat adducted, the interosseous ligament is separated. On further inversion, the tissues being retracted, one may with scissors free the head of the astragalus from its attachment to the navicular, and forcibly twisting it outward, break off the cartilaginous margin to which the internal and posterior ligaments that cannot be reached are attached. One then prepares the new articulation. A thin section of bone is removed from the lateral aspect of the adjoining os calcis and cuboid bones, and from the internal surface of the external malleolus, which may be further shaped to secure accurate apposition. The same, but more difficult, procedure is undertaken on the inner side. One separates the internal lateral ligament from the malleolus sufficiently to permit the complete backward displacement, then removes the cartilage from its inner surface. With the periosteal elevator the strong inferior calcaneo navicular ligament is detached sufficiently to permit the malleolus to sink in behind or to slightly overlap the navicular. Often the sustentaculum tali must be cut away to provide sufficient space for the broad, shallow internal malleolus. The two peronei tendons thoroughly freed from their attachments about the fibula are then passed through the base of the tendo achillis and sutured to it, and to the os calcis as well, at a sufficient tension to hold the foot in moderate plantar flexion. The tendo achillis is usually overlapped and sutured as an aid in restraining deformity. The Esmarch bandage is then removed, the part is thoroughly cleansed with hot saline solution, and the bleeding points are ligatured. The wound is closed with continuous catgut sutures, reinforced at several points with silk. The foot then carefully supported in its attitude of backward displacement and moderate plantar flexion with the malleoli fixed by slight pressure in their new relations, is thickly covered with sterilized sheet wadding and fixed by a light plaster bandage, particular care being taken to exert only the slightest constriction. The leg is then brought to a right angle with the thigh and the plaster bandage is continued over the thigh, reinforced by a band of steel in the popliteal region."

TENDON SHORTENING

A few words should be said about the operative shortening of stretched and elongated tendons in infantile paralysis because it would be such an obviously simple thing to do if effective that it would have a wide application. But in general it is unsatisfactory probably because in most instances the conditions which caused the stretching in the first place are still existent and will cause it again, because paralyzed tendons appear to stretch under continued tension.

The most obvious and well-known failure in this class of operation was the so-called Willet's[1] operation in which the tendo achillis was divided, shortened and sutured in cases of talipes calcaneus due to paralysis of the gastrocnemius, but the muscle stretched and the foot relapsed.

Hoffa devised an operation embodying the same principle in calcaneo-cavus. The os calcis was sawed or chiselled through behind its articulation with the astragalus and set up, while the tendo achillis was reefed. In cases operated on by this method by the writer relapse occurred.

Robert Jones has used an operation for talipes calcaneus of much the same character. The tendo achillis is split longitudinally and pulled apart by retractors exposing the posterior capsule of the ankle-joint. The foot is sharply plantar flexed and this posterior capsule is reefed as closely as possible by an over-and-over silk suture. The tendo achillis is then sewed together by stitches which shorten it by closing the longitudinal opening into a transverse one and the foot put up in the equinus position. Tendon transplantation may be added.

The writer's experience with the reefing alone has been unsatisfactory, many cases relapsing and although in a gastrocnemius partially paralyzed a recovery of power might occur, in a completely paralyzed muscle apparently stretching takes place.

SUMMARY

The operative treatment of the various deformities may be summarized for convenience and are named in the order of the

[1] Alfred Willet: "St. Barth. Hosp. Rep.," 1880, vol. vi.

writer's preference but in the matter of such preference there is ground for a wide difference of opinion among experienced men.

Talipes Equinus.—Stretching, tenotomy of the tendo achillis if the anterior muscles have fair power. Transplantation of the extensor of the great toe or other extensors into the tarsal bones, anterior silk ligaments with or without tenotomy, tenodesis, arthrodesis.

Talipes Calcaneus.—Astragalectomy, tenodesis, arthrodesis.

Talipes Varus.—Transplantation of the anterior tibial when that is active to the outer third of the foot. Silk ligament from the fibula to the cuboid, astragalectomy, tenodesis, arthrodesis.

Talipes Valgus.—Transplantation of one of the peroneals to the inner side of the foot, silk ligaments from the tibia to the inner side of the tarsus, astragalectomy tenodesis or arthrodesis.

Flexed Knee.—Stretching or open division of hamstrings.

Hyperextended knee.—In cases where the quadriceps is paralyzed and the hamstrings and gastrocnemius are good, transplantation of one or two hamstrings into the tubercle of the tibia.

Knock-knee.—Supracondyloid osteotomy (Soutter's operation).

Flexed Hip.—Fasciotomy, if severe.

Dislocated Hip.—Arthrodesis.

Shoulder.—Dropping of the arm away from the glenoid cavity, arthrodesis of the joint, silk ligaments.

In cases of deltoid paralysis with the pectoralis major active the origin of the latter may be transplanted into the spine of the scapula.

Operation in the forearm elbow and wrist cannot be summarized as they vary greatly in individual cases. Arthrodesis of the elbow is useful but the operation is not applicable at the wrist on account of the nature of the joint.

CHAPTER VI

MUSCLE TRAINING

EXAMINATION OF MUSCLES—GAIT—PRINCIPLES OF MUSCLE TRAINING—METHOD—EXERCISES FOR EXAMINATION AND MUSCLE TRAINING

It is obvious that any effective treatment of infantile paralysis, whether it be mechanical, by physical therapeutics, or by operation, *must* be preceded by a careful examination of the function and relative strength of the muscles involved as to whether they are normal, weakened, or unable to perform any function at all. Careless and inexact examination *must* obviously lead to ineffective treatment.

Inasmuch as the question of non-operative treatment is a matter of developing the power of voluntary muscular contraction, the examination should necessarily concern itself with the amount of voluntary contractile power existing in the individual muscles. The examination by electricity gives certain information, but not the specific information which we wish. Such an electrical examination requires expert knowledge, it is difficult to confine the current to the individual muscles, and the result is in terms of contraction to electricity and not of contraction to voluntary impulse. What we want to know practically is the power of contraction to voluntary impulse, and to methods of examination directed to that end the present discussion will be confined.

In any such examination it is important to note the existence of fixed deformity.

GAIT

In proceeding to the examination for the muscular diagnosis it is desirable first to see the patient walk if he is able to do so, because the problem of treatment is most often concerned with the walk and many important facts may be learned by

watching the gait if the patient is able to get about. In many cases a limp will persist through habit after the patient has recovered sufficient muscular power to enable him to walk without one.

The following are some of the most characteristic gaits as modified by paralysis of individual muscles. In the description of each gait it is assumed that all the other muscles are normal, but it should be kept in mind that there can be any combination of paralysis with consequent modification of the limp.

Gastrocnemius.—The walk is heavy, the heel is brought down first and there is no spring when the next step is taken. If one side alone is affected the gait is arrhythmic, the patient pausing longer on the good foot. When both sides are affected the gait is waddling, with the feet turned outward.

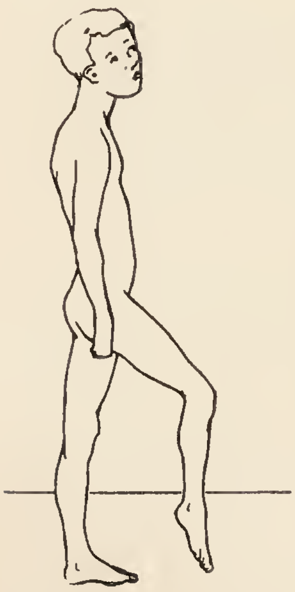

Fig. 79.—Gait in paralysis of dorsal flexors of foot.

Dorsal Flexors of Foot.—The patient lifts the knee of the weak side high in order to clear the toes of the paralyzed foot, which "drop" when lifted from the ground. There is a tendency to extend fully or even hyperextend the knee when the foot is brought down. Weakness in one case was so slight as to escape detection by hand resistance, but the mother reported that the child fell down often, and it was discovered that she was unable to walk on her heels with her toes in the air.

Anterior Tibial.—The patient walks with the weight on the inner border of the foot, which is pronated and everted (talipes valgus).

Peroneals.—When the peroneals are weak the patient walks on the outer side of the foot (talipes varus).

Quadriceps.—With a weakened or paralyzed quadriceps muscle the patient may be able to walk unaided in the following ways:

1. The patient keeps the knee from flexing as he walks by pressing the thigh back with one hand.

2. As the affected foot touches the ground the patient hyperextends the knee, thereby locking the joint.

3. The patient walks with the leg rotated outward.

4. With talipes equinus the foot when placed on the ground locks the knee back because it cannot dorsally flex, and thus the knee is held extended and able to bear weight.

5. With strong hamstrings the patient can lock the knee without hyperextending or even fully extending it, simply by bending the whole body forward, the thighs thus carrying the center of gravity forward.

Gluteus Maximus.—In stepping forward with the foot of the weak side the patient lightly touches the foot to the ground and

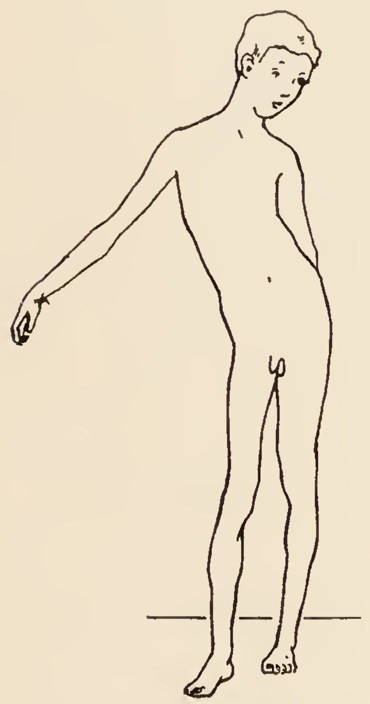

FIG. 80.—Gait in paralysis of gluteus medius of right side.

FIG. 81.—Gait in paralysis of hip flexors.

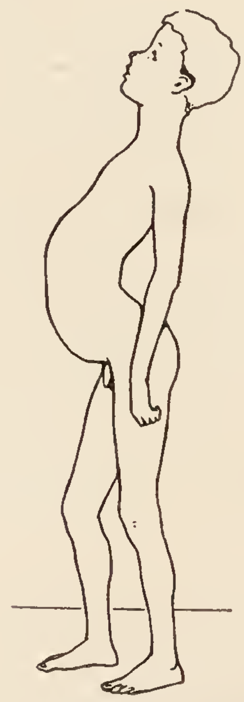

FIG. 82.—Gait with abdominal paralysis.

brings the good foot forward again very rapidly, with the knee of the good leg bent. The limp is very marked on account of the extreme dipping on the *good* side. When both gluteals are badly affected walking without crutches is impossible.

Gluteus Medius (*Hip Abductor*).—A patient with weak abductors in walking takes his weight on the weak leg and tips his whole body toward that side and reaches out the hand for balance. This tipping and reaching out toward the weak side is very characteristic of abductor paralysis. In slighter cases it resembles the gait due to a short leg.

Hip Flexors.—The patient brings the affected limb forward by a forward twist of the pelvis on that side.

Adductors of the Hip.—Weakness of the adductors does not cause a real limp, but it can be detected by asking the patient to place one foot directly ahead of the other in walking. With weak adductors this can only be done by swinging the body.

Abdominal Muscles.—With weak abdominal muscles the patient stands and walks sway-backed, with the hips flexed and the lumbar spine in strong lordosis and with the abdomen prominent. Unilateral paralysis of the abdominal muscles, and especially of the quadratus lumborum, causes the patient to drop the pelvis on the weak side in taking the weight on the good leg. The position is like that taken by a patient with congenital dislocation of the hip when standing on the affected leg (Trendelenberg's sign).

Back Muscles.—Seriously weakened back muscles make it impossible for the patient to hold the spine erect in sitting, standing or walking. There is generally in these cases a lateral deviation of the spine. The more asymmetrical the paralysis the more rapid the onset of the scoliosis.

MANUAL EXAMINATION OF THE MUSCLES

The muscles should be examined individually as to their attempt to contract in response to voluntary impulse. Positions favorable to the contraction of special muscles are chosen, and will be described in detail, and the patient is directed to perform a certain movement. During this movement the muscle under examination or its tendon is carefully watched for evidence of contractile power. There may be no response whatever, there may be a flicker of power, there may be fair but not normal power, or there may be normal power.

By the examination of the individual muscles these facts may be determined and recorded on a chart. The chart used for this purpose and the method of recording such data were devised by Dr. E. A. Sharpe of Buffalo, and have been most satisfactory within their limits. (See Fig. 13.)

In children too young or too unruly to obey such orders, much information, although far less exact, may be obtained by watching the voluntary movements of the child as it lies on

the mother's lap or on a table and analyzing them so far as possible. Movement may be stimulated by means of tickling or irritating the skin of the sole, the calf or the thigh, and by shifting the position of the child during this and during spontaneous movement and struggling, and for the arm movements by holding out toys to be grasped. In these ways information may often be obtained which will throw light on the general distribution of the weakening or paralysis.

It is very important for purposes of prognosis to distinguish as far as possible the action of individual muscles engaged in performing one movement. Suppose, for example, the power of the muscles flexing the elbow be represented in one case as 4, in which 1 stands for forearm muscles and 3 for biceps, and in another case as 4 also, of which 3 stands for forearm muscles and 1 for biceps, then in the first case we might reasonably expect a much better return of flexion power than in the second, as the biceps is much the more important flexor of the elbow.

The method of examination described is not a mathematically accurate one, but it has the advantage of requiring no apparatus and of providing a graded series of tests for estimating muscular power.[1]

EXERCISES FOR MUSCLE TRAINING

When the muscles have been examined by the method to be described, a set of exercises should then be worked out to suit the individual case and these exercises are given in connection with each movement and follow directly after the examination of each region. Naturally they are often the same as the examination.

If a muscle is apparently without any power, the patient should concentrate his attention on the attempt to accomplish the movement while it is performed passively. It often happens that weak muscles may be able to carry the limb through only a part of its normal are of motion. In such a case the limb should be carried by the surgeon passively through the remaining arc of motion normal to the joint and there should

[1] The anatomical authorities followed in the action of the leg muscles have been Cunningham and Piersol. When they have differed as to the function of a special muscle, the author has been quoted who credits it with that function.

be no pause after the muscle has ceased acting, but the assistance should come in time to make one smooth movement throughout the whole arc, in order that there may be no interruption in the patient's mental effort. Not until muscles are capable of performing a movement through its whole arc should any additional resistance be given, and not until they are capable of performing the movement next in order of strength throughout its whole arc, should that movement be given in place of the easier one.

When resistance is given, it should be graduated from weak at the beginning of the movement to strong in the middle, and to weak again at the end of the movement, in accordance with the change in leverage that takes place during the movement. The resistance at every point should be just a little less than would stop the movement.

It is usually enough to let the patient go through all his exercises once a day six days in the week. The one day of rest prevents him from becoming stale. Each exercise may be performed ten or twelve times in succession in slow enough rhythm to allow for complete recovery between efforts. Unless it is done as well the second time as the first and the tenth as well as the second it is being done too fast and the patient should be given a rest at once. A few seconds are usually enough for recovery between successive attempts.

If possible the patient should never be left to do his exercises alone, even when he is old enough to understand his own case. The response of muscle and nerve is dependent on the strength of the stimulus and the volition of the patient is greatly aided by the outside stimulus of a word of command. If the patient is a child the schemes for exciting interest and concentrating the attention on the effort to be made have to be varied every day, but there should not be any sacrifice of precision in the performance of the exercises. If the child is too young to make any intelligent effort at formal exercises the ingenuity of the mother will usually discover a means of bringing the affected muscles into play if she is made to understand what is required. Accuracy and precision are of the utmost importance in obtaining a proper result. Carelessly

performed exercises are of little value. In all exercise periods the whole attention of the patient should be required and it is desirable that no person except the one who directs the exercises should be present—certainly no other child.

While performing the exercises the paralyzed limbs should be uncovered, as the action of the muscles cannot be accurately observed through clothing. When the paralysis is extensive, the patient, if a young child, should be entirely undressed for a treatment.

A table or other hard, smooth, horizontal surface, preferably not the floor, is necessary for the proper performance of the exercises, as it eliminates as much as possible the resistance of friction and enables a weak muscle to perform movements which would be wholly impossible for it on a soft yielding surface like that of a bed or couch.

The regions will next be taken up separately, the examination for each region given and the exercises to be prescribed will follow the examination in each region.

The tests and exercises have been arranged in the order of their strength, those for normal or nearly normal muscles being given first.

LOWER EXTREMITY

The Foot

Toes—*Flexion.*—Flexion of the toes is produced by the following muscles: flexor longus digitorum, four toes (acting on both joints); flexor brevis digitorum, four toes (acting on the first joint); flexor accessorius, four toes; flexor longus hallucis, big toe; flexor brevis hallucis, big toe; flexor brevis minimi digiti, one toe; lumbricales, four toes; interossei, three toes.

Examination for Toe Flexion.—1. The patient lies on the back or sits and bends the toes toward the sole of the foot, to "make a fist" with the foot. Complete paralysis of all toe flexors is rare.

Exercises for Toe Flexors.—101. The movement described in 1 (see Examination) is performed (*a*) with resistance and (*b*) without resistance from the surgeon, who places one finger across underneath the toes and pushes up against them.

Toes—*Extension.*—Extension is produced by the following muscles at the metatarso phalangeal joints: extensor longus digitorum; extensor brevis digitorum; extensor proprius hallucis; interossei; lumbricales (Cunningham).

Examination.—2. The patient sits or lies on the back and bends the toes toward the dorsum of the foot. The surgeon may resist the movement with one finger placed on the dorsal surface of the toes. Normal toe extensors should be able to overcome considerable resistance.

Exercises.—102. The patient performs the movement described in 2 (*a*) with resistance, (*b*) without resistance.

Ankle—*Dorsal Flexion* (Flexion).—Dorsal flexion of the foot is produced by: tibialis anticus; extensor longus digitorum (Piersol); extensor communis digitorum (Cunningham); extensor proprius hallucis; peroneus tertius.

Examination.—3. The patient stands on the foot to be tested and raises the front of the foot from the ground until he is balanced on the heel. For the performance of this motion the tibialis anticus and other muscles must be nearly normal. The toe extensors alone probably do not have power enough to perform this movement. (See Fig. 83.)

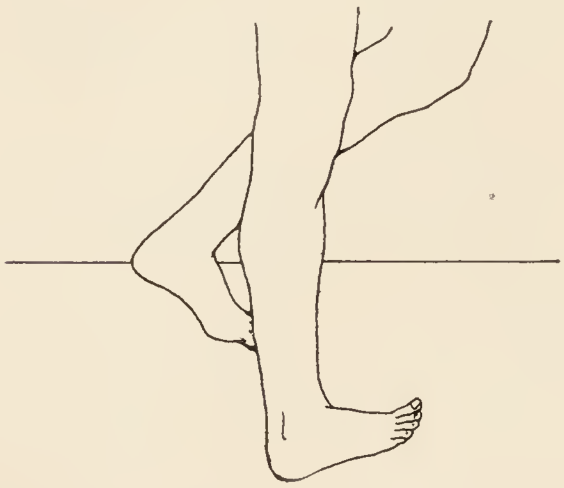

Fig. 83.—Examination No. 3, dorsal flexion.

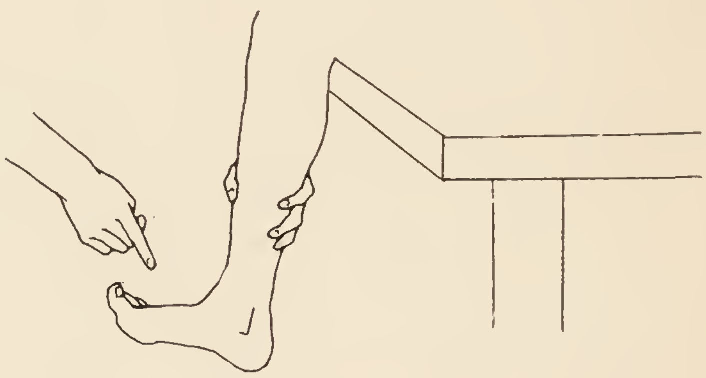

Fig. 84.—Examination No. 4, dorsal flexion.

4. The patient sits with the feet hanging free and tries to raise the foot against resistance on the dorsum, the leg being steadied. If the foot can be raised above a right angle in this position but 3 cannot be performed the muscles are not normal but may be classed as good. If they cannot perform it gravity must be eliminated as in the following test. (See Fig. 84.)

5. The patient lies on the affected side with the affected leg held firmly down on the table and the foot in plantar flexion and attempts to bring it into dorsal flexion. If the muscles act only in this position, they are very poor; if they do not act, they are paralyzed. Care must be taken not to confuse the rebound from extreme plantar flexion with real action of the dorsal flexors.

Exercises.—103. The patient performs the movement described in 3.

104. The patient performs the movement described in 4 with and without resistance.

105. The patient lies on the affected side and dorsally flexes the foot while the leg is held firmly down on the table. This eliminates pronation of the foot.

106. The patient lies on the face with the knee flexed at right angles and the lower leg directed vertically upward. The surgeon studies the leg during attempted dorsal flexion of the foot (*a*) with the finger under the dorsum of the foot resisting the movement; (*b*) with gravity assisting the movement.

Plantar Flexion (Extension) *of the Ankle.*—The muscles concerned are: gastrocnemius; plantaris; soleus; tibialis posticus; peroneus longus and brevis; flexor longus digitorium; flexor longus hallucis.

Examination.—6. The patient stands on the affected side with the sound knee bent and steadied by holding the surgeon's hands with his own, rises on the ball of the affected foot (attempts to stand on tip toe). Normal plantar flexors can raise the body weight about ten times without flagging.

7. The patient walks on tip toes. An affected muscle may be strong enough to permit this when it is too weak to perform the preceding movement. (See Examination 6.)

8. The patient lies on the face with the feet projecting over the end of the table and attempts plantar flexion against the resistance of the surgeon's hand. When a patient is unable to stand, this test will indicate the amount of power in the muscles involved. (See Fig. 85.)

9. The patient lies on the affected side with the leg held and attempts plantar flexion at the ankle. The tendo achillis must be closely watched in this

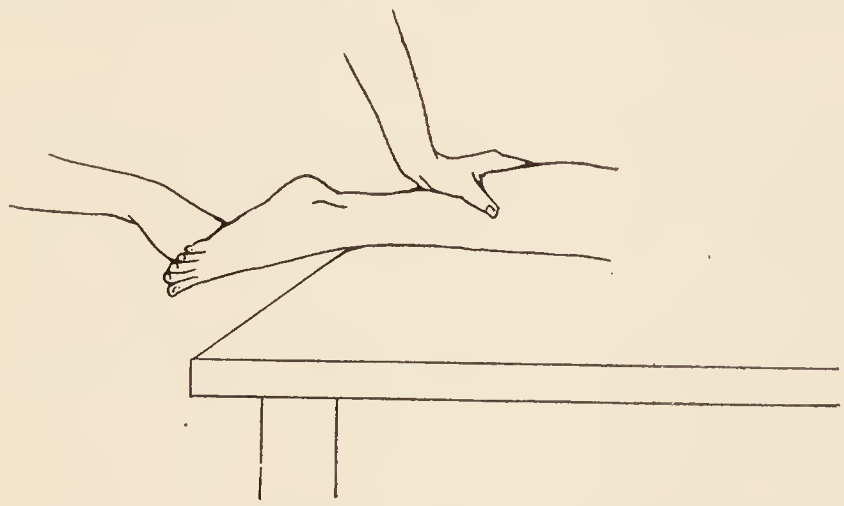

FIG. 85.—Examination No. 8, plantar flexion.

attempted movement to see if any contraction of it occurs, as the tibial, peroneal, or long toe flexor may cause slight plantar flexion when the gastrocnemius is wholly paralyzed and in the latter case the outlook is less good.

Exercises.—107. The movement is described in 6. (See Examination.)

108. The movement is described in 7.

109. The movement is described in 8.

110. The patient performs the movement described in 9: (*a*) with resistance, (*b*) without resistance on the sole of the foot.

111. The patient lies on the face with the knee flexed to a right angle and the lower leg directed vertically upward and plantar flexes the foot, (*a*) without assistance, (*b*) with assistance on the dorsum of the foot.

Inversion of the Foot.—The muscles concerned are: Tibialis anticus; tibialis posticus.

When the anterior tibial is paralyzed the extensor longus hallucis acts with some slight force to invert the foot.

Examination.—10. The patient lies on the affected side and while the leg is held firmly down on the table lifts the outer border of the foot away from the table with resistance from the hand on the inner border of the foot. To perform

this movement both tibials must be very good and it is important to look for and identify the tendon of each when this movement is attempted for even with very weak muscles the tendons may be seen to contract. The peroneals must be relaxed before the movement is attempted as otherwise the rebound from their contraction might be taken for active movement. In case the extensor longus hallucis is acting to replace the tibialis anticus its tendon will be felt instead of the tibial tendon; normally both can be felt lying close together, the tibial tendon nearer the internal malleolus.

Fig. 86.—Test for tibialis posticus.

Fig. 87.—Test for tibialis anticus.

Figs. 86 and 87.—Examination No. 11.

11. The patient sits with the foot hanging free, with the lower leg held firmly and turns the foot inward in an attempt to touch the surgeon's finger which is first held slightly above the great toe on the inner border of the foot (tibialis anticus) and then held slightly below the inner great toe joint (tibialis posticus). (See Figs. 86 and 87.)

Exercises.—112. The patient attempts the movement described in 10, (*a*) with resistance on the inner border of the foot, (*b*) with help at the end of the movement. (See Fig. 88.)

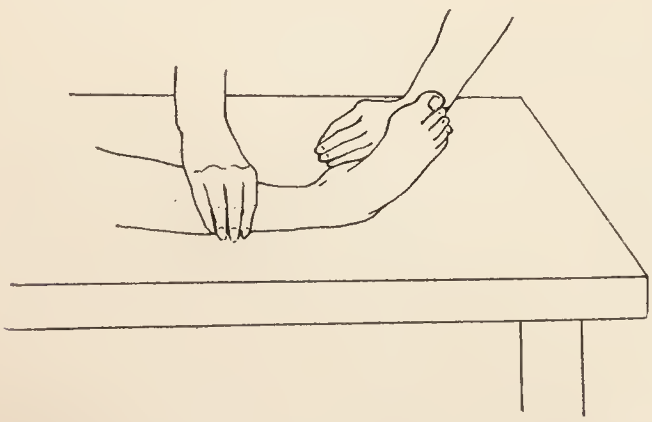

Fig. 88.—Exercise 112, inversion of foot.

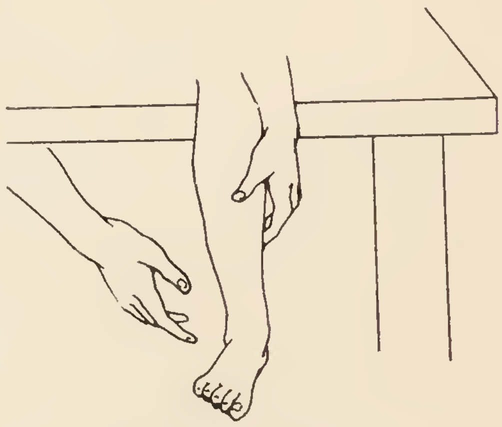

Fig. 89.—Examination No. 12, eversion of foot.

113. The patient sits on the edge of the table with the legs hanging down and the leg steadied by the surgeon. He then attempts to turn the front of the foot inward and upward toward the other ankle, (*a*) with resistance against the inner border of the foot, (*b*) with the resistance of gravity alone.

114. The patient lies on his back, the surgeon holding the affected leg above the ankle to steady it and turns the foot inward toward the other ankle, (*a*) without help, (*b*) with help in accomplishing the movement.

Eversion of the Foot.—The muscles concerned in this are: peroneus longus; peroneus brevis; peroneus tertius.

The extensor longus digitorum in the weakness of tibial muscles acts as an evertor of the foot.

Examination.—12. The patient sits with the foot hanging free, the lower leg steadied by the hand, and turns the foot outward to touch the surgeon's finger. (See Fig. 89.)

Exercises.—115. The patient sits as described in 12 and everts the foot, (*a*) against manual resistance, (*b*) with the resistance of gravity alone.

116. The patient lies on his back with the affected leg held and turns the sole of the affected foot outward away from the other foot.

Knee.—*Flexion.*—The muscles performing this movement are: biceps; semitendinosus; semimembranosus; gastrocnemius; popliteus; sartorius; gracilis (Cunningham).

Examination.—The hamstrings which are the principal knee flexors are also, it must be remembered, extensors of the hip and for this reason are more power-

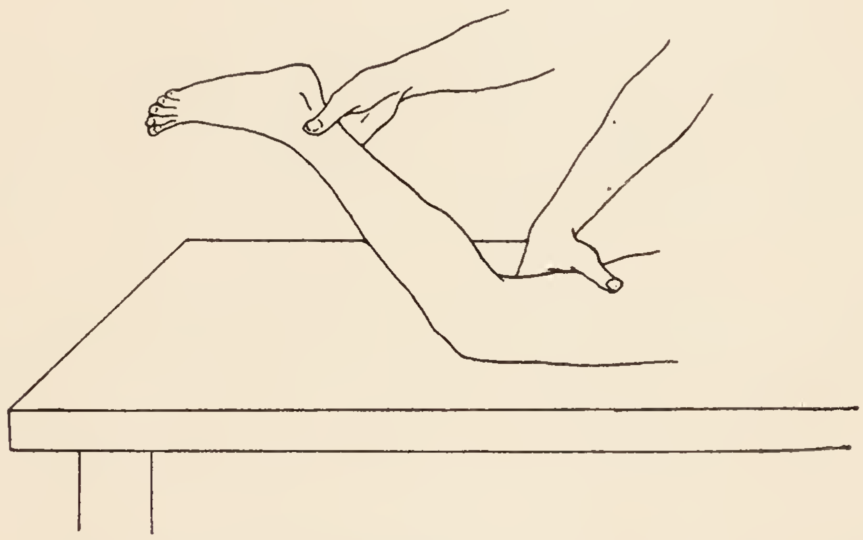

FIG. 90.—Examination No. 13, knee flexion.

ful than would be the case if their sole function were to lift the weight of the leg in flexing the knee in walking.

13. The patient lies face downward and flexes the knee from the straight position until the heel touches the buttock, while the surgeon offers resistance over the back of the ankle. Considerable resistance can be overcome if the muscle is normal. If it cannot raise the weight of the leg, it is poor and gravity must be eliminated as in the next exercise. (See Fig. 90.)

14. The patient lies on the affected side with the hip flexed and the knee extended while the thigh is held firmly and attempts to flex the knee. If the muscles show no power in this position they must be classed as paralyzed and much information may be gained by feeling of their tendons during attempted movement. Paralysis of the gastrocnemius weakens the force of knee flexion even with normal hamstrings. The inner or outer hamstring may be paralyzed while the other will contract. (See Fig. 91.)

Exercises.—117. 13 describes this exercise. It should be done, (*a*) with resistance at the back of the ankle, (*b*) with the resistance of gravity.

118. The exercise is the same as the examination in 14, (*a*) with resistance from

the surgeon's hand on the back of the ankle, (*b*) by unaided muscular contraction (*c*) with assistance on the front of the ankle.

119. The patient lies on the back while the surgeon holds up the affected leg steadying the thigh in the vertical position and offers resistance on the back of the leg as the patient flexes the knee. In this exercise gravity assists the move-

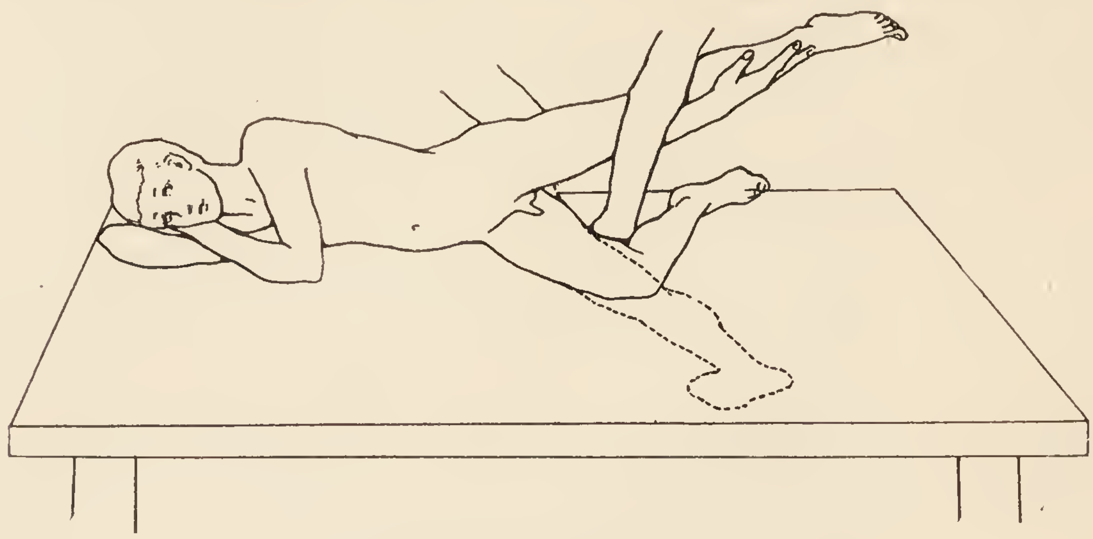

FIG. 91.—Examination No. 14, knee flexion.

ment and it is possible to add just the amount of resistance necessary to overcome gravity and as much more as can be overcome by the weakest muscles.

Extension of the Knee.—The extensor of the knee is the quadriceps extensor.

Examination.—15. The patient sits on the heels, shifts all the weight onto the leg to be tested and comes up to the erect position on that leg, steadying himself

FIG. 92.—Examination No. 15, knee extension.

by holding the surgeon's hands. The muscle is normal if this movement can be performed with slight assistance. (See. Fig. 92.)

16. The patient sits on a table with the knees flexed and the legs hanging over the table and attempts to extend the knee against resistance on the front of the ankle. The amount of resistance required to stop the movement will enable

the surgeon to judge its power especially if the muscle on the other side is normal and can serve as a comparison. If the quadriceps cannot raise the weight of the leg, it is poor.

17. The patient lies on the affected side with the hip fully extended and the knee flexed and attempts to straighten the knee. If no contraction is found in this position the muscle must be classed as wholly paralyzed. (See Fig. 93.)

Exercises.—120. The patient performs movement 16, (*a*) with resistance from the surgeon on the front of the ankle, (*b*) with the resistance of gravity alone.

121. The patient performs 17, (*a*) with resistance on the front of the ankle, (*b*) unaided, or (*c*) with assistance.

122. The patient lies on the face with the knee flexed to a right angle and extends the knee against resistance.

123. The patient lies face down on a table with the hips flexed and legs hanging over the edge of the table. The surgeon steadies the affected thigh with his hand and with his other hand flexes the knee and holds it in front of the ankle while the patient attempts to extend the knee with the help of gravity.

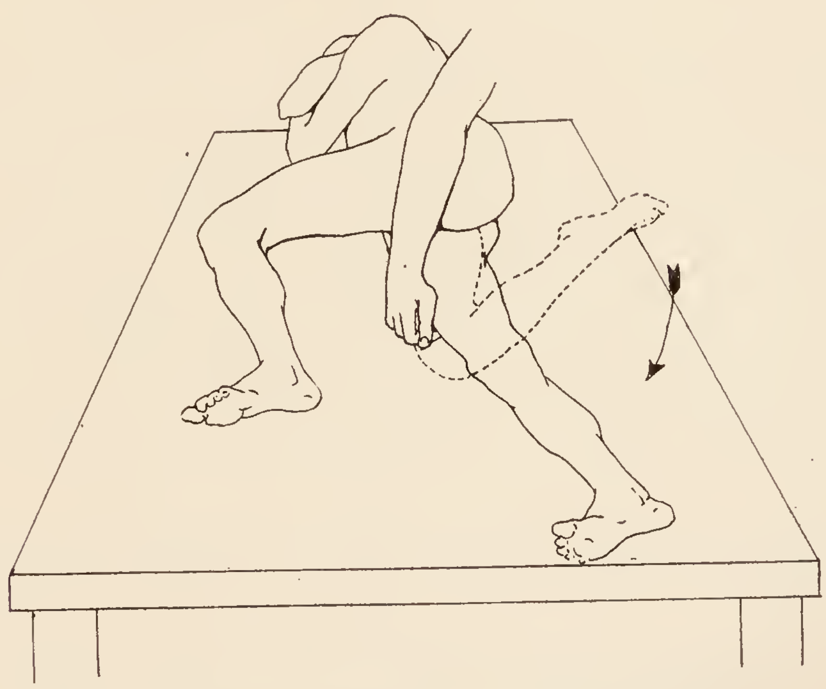

FIG. 93.—Examination No. 17, knee extension.

Hip.—*Flexion.*—The muscles performing this movement are: sartorius; psoas major and iliacus; rectus femoris; pectineus; adductor longus; gracilis; obturator externus (Piersol); adductor brevis (Cunningham).

Examination.—18. The patient sits with the lower legs hanging over the edge of a table and raises the knee to the chest with resistance at the front of the thigh just above the knee. Normal muscles should overcome much resistance. (See Fig. 94.)

19. The patient lies on the affected side, the surgeon supporting the other leg and attempts to draw the knee up to the chest. Muscles which show no power in the position must be counted as paralyzed. (See Fig. 95.)

During this movement it may be possible to distinguish between the contraction of the sartorius and rectus femoris by placing one finger on the anterior superior spine and one on the inferior and feeling from which of them the contracting muscle originates.

124. The patient performs 18, (*a*) with resistance, (*b*) without resistance.

125. The patient lies on his back and brings his knee up to his chest, (*a*) with resistance, (*b*) without other resistance than the weight of the leg.

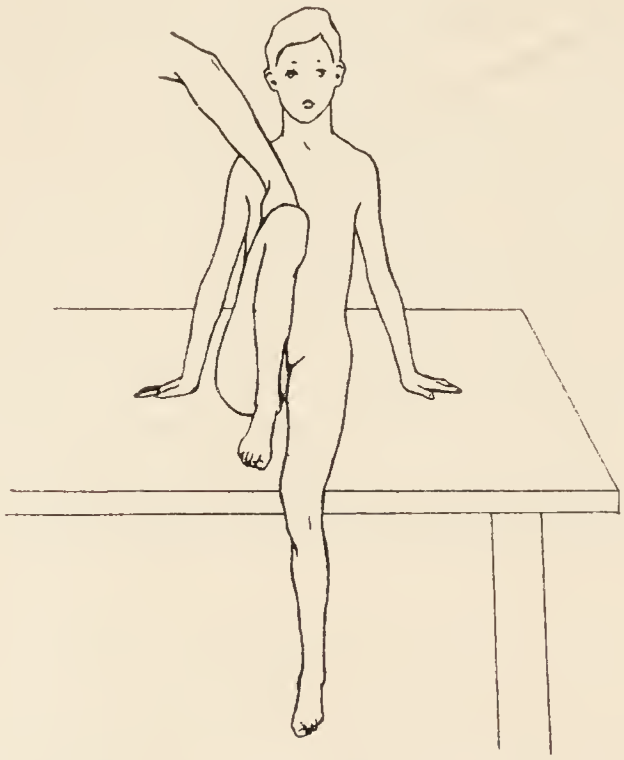

FIG. 94.—Examination No. 18, flexion of hip.

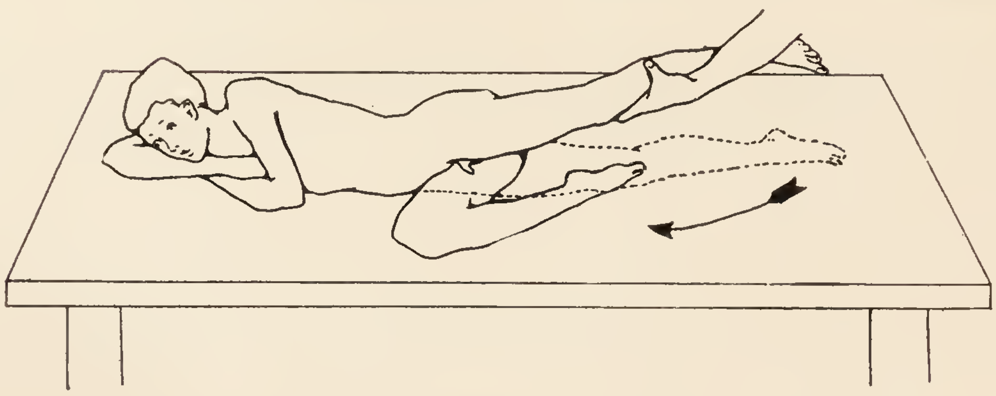

FIG. 95.—Examination No. 19, flexion of hip.

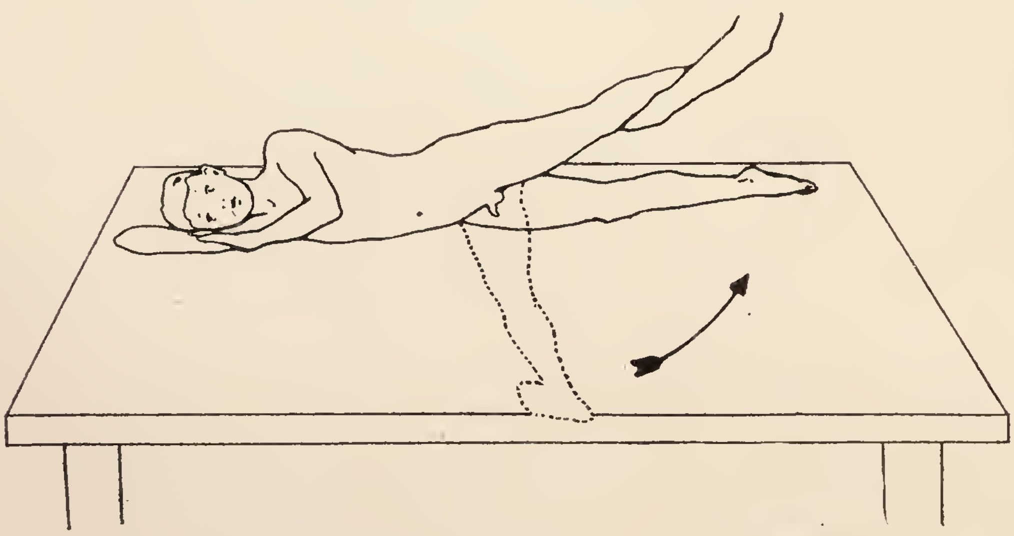

FIG. 96.—Examination No. 21, extension of hip.

126. The patient performs 19, (*a*) with resistance against the front of the thigh, (*b*) without resistance, (*c*) with assistance.

Exercises.—127. The patient lies face down on a table with the legs hanging over the edge, being flexed at the hip-joints. The affected leg is then raised to the horizontal by the surgeon and from this position the patient flexes the hip with the surgeon supporting as much of the weight of the leg as may be required.

Extension of Hip.—The muscles performing this movement are: gluteus maximus; hamstrings; gluteus medius (Cunningham); gluteus minimus (Cunningham); adductor magnus (Cunningham).

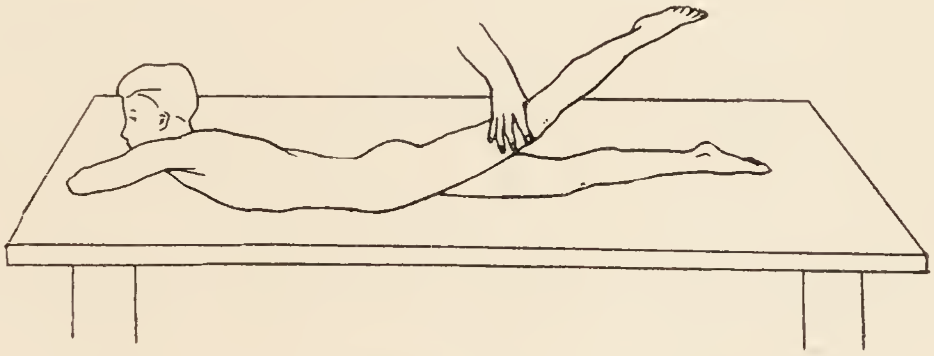

FIG. 97.—Examination No. 20, extension of hip.

Examination.—20. The patient lies on the face and hyperextends the hip with the knee straight, raising the leg from the table. Considerable resistance can be overcome by normal muscles. (See Fig. 97.)

21. The patient lies on the affected side with the hip fully flexed and moves the thigh back into the line of the body. If there is no movement in this position the muscles must be considered paralyzed. Slight power to extend the hip may be found where the gluteals are paraly zed and only the hamstrings acting. (See Fig. 96.)

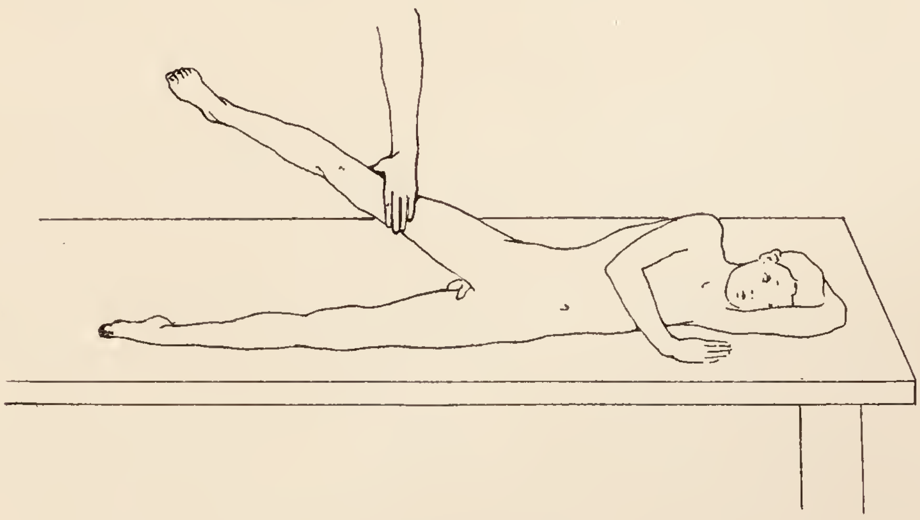

FIG. 98.—Examination No. 22, abduction of hip.

Exercises.—128. The patient performs 20, (*a*) with resistance, (*b*) without resistance—without twisting the body.

129. The patient lies face downward on a table with the hips flexed over the edge and the legs hanging down. In this position he raises the leg to the horizontal, (*a*) with the resistance of gravity alone, (*b*) with resistance on the back of the thigh.

130. The patient performs 21, (*a*) with resistance, (*b*) unaided, (*c*) with assistance.

131. The patient lies on the back and the affected leg with the knee straight

is lifted as high as possible by the surgeon and the patient brings the leg back to the table with the surgeon making as much resistance as can be overcome.

Abduction of the Hip.—The muscles concerned are as follows: gluteus medius; gluteus minimus; tensor fasciæ femoris (Cunningham); obturator externus (Cunningham); during flexion, pyriformis, obturator internus, gemelli; sartorius, gluteus maximus (upper fibers) (Cunningham).

Examination.—22. The patient lies on the sound side and raises the affected leg with the knee straight and in line with the body. The normal muscle overcomes considerable resistance. (See Fig. 98.)

23. The patient lies on the back with the pelvis firmly held to prevent throwing of the body and abducts the affected leg. Outward rotation of the foot must be checked or flexors will be substituted for abductors.

24. In order to eliminate the possibility that friction of the heel on the table may overcome weak muscles the leg may be slung by a bandage under the ankle, the upper end being held by the surgeon, and the same movement attempted. If no motion occurs, the abductor muscles are paralyzed.

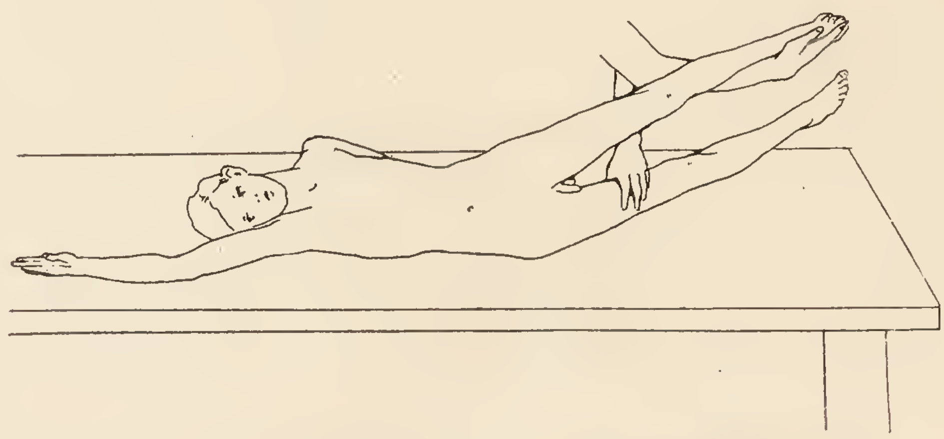

FIG. 99.—Examination No. 25, adduction of hip.

Exercises.—132. The patient performs 22, (*a*) with resistance, (*b*) without resistance.

133. The patient performs 23, (*a*) with resistance, (*b*) without resistance, (*c*) by aid of a sling. (See Examination 24.)

Adduction of the Hip.—The muscles performing this movement are: adductors longus, magnus, brevis; gracilis; pectineus; quadratus femoris (Cunningham); gluteus maximus (lower fibers) (Cunningham).

Examination.—25. The patient lies on the affected side with the sound leg held by the surgeon in a position of abduction. He then raises the affected leg from the table in line with the body with the knee straight and without rotating it. Considerable resistance can be overcome. (See Fig. 99.)

26. The patient lies on the back with the affected leg in extreme abduction and brings it in to the other leg.

27. To eliminate friction a sling may be used and the movement of adduction attempted. (See Examination 24.)

Exercises.—134. The patient attempts the movement described in 25, (*a*) with resistance, (*b*) without resistance.

135. The patient lies on the back with the knees and hips flexed, with the soles resting on the table and the knees apart and attempts to bring the knees together, (*a*) with resistance against the inner side of the knees, (*b*) with only the resistance of gravity.

136. As in 26, (*a*) with resistance, (*b*) unaided, (*c*) by the use of a sling.

Inward Rotation of the Hip.—The muscles are: tensor fasciæ latæ; gluteus medius (anterior fibers); gluteus minimus (anterior fibers); semitendinosus (Piersol); semimembranosus (Piersol); gracilis (Piersol); iliopsoas (Piersol).

These muscles are all concerned also with other functions which have been mentioned in earlier sections.

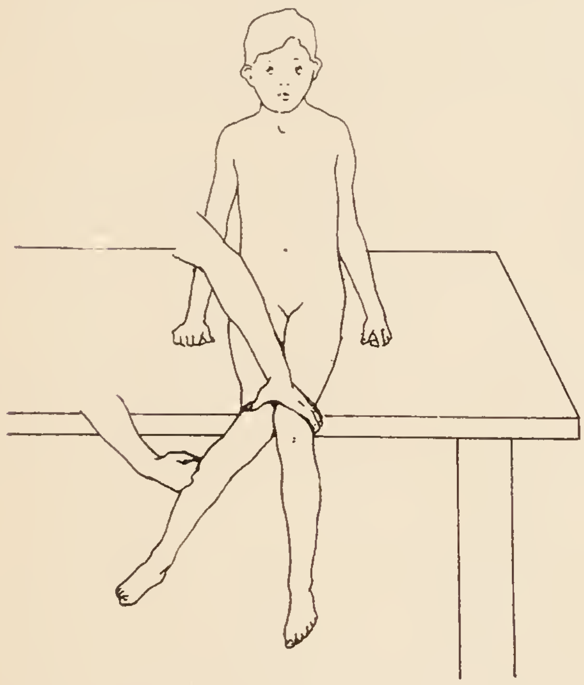

Fig. 100.—Examination No. 28, inward rotation of hip.

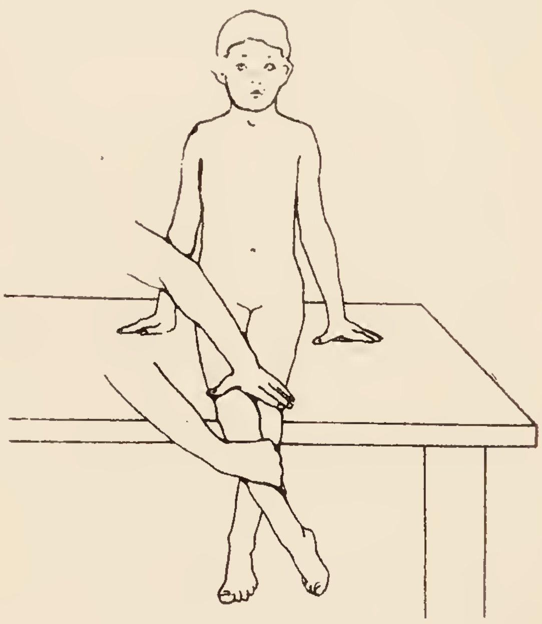

Fig. 101.—Examination No. 31, outward rotation of hip.

Examination.—28. The patient sits with the knees flexed and the lower legs hanging over the edge of a table, keeping the knees together he moves the affected foot away from the other foot, thus rotating the thigh inward. Resistance is offered on the outer side of the ankle. (See Fig. 100.)

29. The patient lies on the back and rotates the whole leg inward. The feet should be somewhat separated and rotated outward at the start.

Exercises.—137. The movement described in 28 is performed, (*a*) with resistance, (*b*) with the resistance of gravity alone.

138. As in 29, (*a*) with resistance, (*b*) without resistance.

Outward Rotation of the Hip.—This is performed by the following muscles: gluteus maximus (lower fibers); gluteus medius (posterior fibers) (Cunningham); gluteus minimus (posterior fibers) (Cunningham); quadratus femoris; during extension, obturator externus, pyriformis, gemelli; sartorius; iliopsoas (Cunningham); pectineus; adductors magnus, longus, brevis, (Cunningham); biceps femoris; obturator internus.

The action of the iliopsoas is given by Piersol as an inward rotator and by Cunningham as an outward rotator.

Examination.—30. The patient lies on the face with the knees flexed, the lower legs upright and the knees touching and the feet are allowed to fall apart. The legs are then rotated so as to bring the feet together.

31. The patient sits at the edge of the table with the knees flexed and the feet hanging down. The foot of the affected leg is then moved inward across the other leg twisting the thigh outward. (See Fig. 101.)

Exercises.—139. 31 is performed, (*a*) with resistance, (*b*) without resistance.

140. The patient lies on the back with the knees straight and legs slightly separated, the toes pointed up and the pelvis held to prevent rolling and turns the whole leg outward, (*a*) with resistance, (*b*) by unaided muscular contraction, (*c*) with assistance.

Spinal Column—*Flexion of the Spine* (Forward Bending).—The muscles concerned are: rectus abdominis; pyramidalis (Cunningham); obliquus externus; obliquus internus; transversus abdominis (Cunningham); psoas major and minor.

Examination.—32. The patient lies on the back with the arms folded, the thighs being held down by the surgeon and attempts to assume the sitting position.

If the muscles are normal the ensiform cartilage is drawn toward the symphysis by the recti, assisted by the other abdominal muscles, thus flexing the lumbar spine; then the psoas and iliacus and other hip flexors flex the pelvis on the thighs. If the hip flexors are paralyzed, normal abdominal muscles cannot raise the patient to a sitting position, but by placing the hand over them as they contract it is possible to feel them hard and to judge by their tone and by the ease with which the lumbar spine is flexed whether or not they are normal. If, on the other hand, the recti are paralyzed and the hip flexors normal, the patient will first fix the lumbar spine by contracting the erector spinæ muscles and then flex the pelvis on the thighs with the back hollowed and the abdomen prominent and soft. The abdominal muscles of one side may be affected more than those of the other, a fact which may be ascertained by feeling the muscles of either side as they attempt to contract and by watching to see whether the umbilicus is drawn to one side or the other.

Exercises.—141. The patient sits in a semireclining position with the back against a slanting support, with arms folded and knees held down and tries to assume a sitting position. The resistance is offered by the weight of the body and the exercise may be made more difficult by starting from a position of the trunk nearer the horizontal.

142. The patient lies on the back and flexes the knees onto the chest, if necessary with assistance under the knees.

143. The patient lies on the side with the arms folded on the chest and the hips firmly held and flexes the spine by bending the body forward. Resistance is offered by the friction of the body on the table. This exercise should be done with the patient lying first on one side and then on the other.

Extension of the Spine.—Produced by the contraction of the *erector spinæ*, a name used here to describe the whole group of posterior spinal muscles instead of the complicated more modern nomenclature given in Piersol and

Cunningham. These muscles cannot be exercised without at the same time exercising the extensors of the hips.

Examination.—33. The patient lies on the face with the legs held down by the surgeon, and tries to raise the head and trunk from the table.

If the erector spinæ muscles are normal they can bend the spine backward and raise the head, shoulders and whole body clear of the table and can be felt as two prominent columns on each side of the spine. When they are not strong enough to lift the weight of the body, they may be still felt to contract by placing the fingers on each side of the spine. It is not easy to eliminate gravity in testing these muscles, so that their presence or absence must be judged by whether or not they can be felt contracting when the patient attempts to lift the body. Frequently the muscles of one side are good, while those of the other are paralyzed or very weak. In such a case the patient always sits or stands, and sometimes even lies with the spine curved laterally, although a lateral curvature may occur also as a result of asymmetrical abdominal weakness.

Exercises.—144. The patient performs the movement described in 33. Resistance is furnished by the weight of the trunk.

145. The patient sits with the trunk bent forward, the hips flexed and raises the trunk to the erect position, (*a*) with the hands behind the neck and the elbows squared (the stronger exercise), and (*b*) with the hands on the hips (the weaker exercise).

Lateral Flexion of the Spine (*Side Bending*).—The most important muscles taking part in this movement, which is not to be clearly separated from the following movement of rotation, are as follows: rectus abdominis; obliquus externus and internus; transversus abdominis; erector spinæ; psoas major and minor; quadratus lumborum.

Examination.—34. The patient lies on the unaffected side, the legs in line with the body and held down by the surgeon with the arms folded and attempts to lift the body up from the table. This is easily accomplished if the muscles are normal. If they are very weak, the muscles on the other side will contract and the affected side of the body will be arched up from the table between the hip and shoulder.

35. The patient lies on the back with the arms folded, the hips being held firmly by the surgeon and attempts to bend the body toward the side to be tested.

Exercises.—146. The patient performs 34.

147. The patient performs 35.

148. The patient stands and raises the foot of the affected side from the floor without bending the knee, or the patient lies on the face and draws the affected side of the pelvis up toward the shoulder of the same side keeping the knee straight and dragging the leg up along the table, (*a*) with resistance on the ankle, (*b*) without resistance.

Rotation of the Spine.—It has been mentioned that this movement is not clearly to be separated from lateral flexion. The muscles chiefly concerned are: erector spinæ; obliquus externus and internus.

Examination.—36. The patient sits with arms folded, the hips held firmly, and twists the body to one side, (*a*) with resistance, (*b*) without resistance.

Exercises.—149. See 36.

In formulating the movements of the arm Beevor's[1] Croonian lectures on muscular movements have been used as the basis of the analysis and have proved of the greatest use.

UPPER EXTREMITY

The Hand.—*Fingers.*—The examination of the fingers and exercises for weakened muscles will be dealt with only in general for the sake of brevity

FIG. 102.—Test for finger flexion.

and because the examination of the different motions is perfectly obvious and the exercises similarly simple. An attempt should be made to perform the various movements with slight resistance offered by the surgeon and the exercises are similarly given. The opposing and adducting muscles of the thumb should be examined with care in every case whether

FIG. 103.—Test for thumb adduction.

the hand appears involved or not as involvement of these muscles is extremely common.

The function of the different groups is given by Cunningham[2] as follows:

Flexion.—Flexor digitorum sublimis; flexor digitorum profundus; lumbricales; interossei (acting on the metacarpo-phalangeal articulations; flexor digiti quinti brevis).

[1] Chas. E. Beevor, M. D., London, F. R. C. P.: "The Croonian Lectures on Muscular Movements and Their Representation in the Central Nervous System," London, Adlard & Son, 1904.

[2] Cunningham's "Text Book of Anatomy," Robinson, N. Y., Wm. Wood & Co., 1913.

Extension.—Extensor digitorum communis; extensor indicis proprius; extensor digiti quinti proprius; lumbricales; interossei (acting on the interphalangeal articulations).

Abduction.—Lumbricales; flexor brevis and opponens digiti quinti (from the medial side of the hand); dorsal interossei (from middle line of middle finger).

Adduction.—Palmar interossei (to the middle line of the middle finger).

Thumb.—*Flexion.*—Opponens pollicis (carpo-metacarpal joint); flexor brevis, adductor, abductor brevis (carpo-metacarpal and metacarpo-phalangeal joint); flexor pollicis longus (all joints).

Extension.—Abductor pollicis (carpo-metacarpal joint); extensor pollicis brevis (carpo-metacarpal and metacarpo-phalangeal joint); extensor pollicis longus (all joints).

Adduction.—Adductor of the thumb; flexor pollicis brevis; opponens pollicis; first dorsal interosseous.

Abduction.—Abductor pollicis brevis; extensors of the thumb.

Circumduction.—A combination of the above muscles.

Wrist.—*Flexion.*—This motion is performed by the following muscles: flexor carpi radialis; flexor carpi ulnaris; palmaris longus; long flexors of thumb and fingers.

Examination.—37. The patient sits with the forearm supported on the table and the hand extending over the edge with the palm up. The wrist is flexed against the surgeon's resistance. The finger flexors will assist the wrist flexors proper if the fingers are flexed in the palm of the hand.

38. The forearm and hand are supported, ulnar side down, on a table with the wrist hyperextended and an attempt is made to flex the wrist.

Exercises.—These are the same as the examination.

Extension of the Wrist.—The muscles are: extensor carpi radialis; extensor carpi ulnaris; extensors of the thumb and fingers.

Examination is the reverse of that described in 37 and 38 and the **exercises** are the same movements as described in 37 and 38 reversed.

Abduction of the Wrist.—Muscles: Flexor carpi radialis; extensors of wrist and thumb. Extensor carpi radialis longior (Piersol.)

Adduction.—Flexor carpi ulnaris; extensor carpi ulnaris.

Examination.—39. The patient sits with the arm resting on a table, ulnar side down, and the movements of adduction and abduction are tested by the surgeon who resists each attempted movement.

40. If the muscles are too weak to give satisfactory information in this position the forearm should rest on the table, palm up, and adduction and abduction be tested (*a*) with resistance, (*b*) unaided.

Exercises.—These are described under examination.

Pronation of the Forearm and Hand.—The muscles concerned are: pronator radii teres; pronator quadratus; flexor carpi radialis.

(The brachioradialis (supinator longus) is given as a pronator from extreme supination by Cunningham but is regarded purely as a flexor by Beevor and is considered to have also slight supinator power by Piersol. The view of Beevor will be followed here.)

Examination.—41. The patient sits with the forearm resting on the lap, palm up. The surgeon grasps the hand and resists pronation. The exercise is given without resistance when the muscles are very weak. The **exercises** are the same

Supination of the Forearm and Hand.—Supinator (supinator radii brevis); biceps; brachioradialis (Cunningham).

Examination.—42. The patients sit with the forearm resting on the lap, palm down. The surgeon grasps the hand and resists attempted supination. The test is given without resistance when the muscles are very weak. (See Fig. 104.)

Fig. 104.—Examinations Nos. 41 and 42, test for pronation and supination.

As the biceps is a powerful flexor as well as supinator, when it is weakened, strong supination will be accompanied by extension at the elbow and when the triceps is weakened and the biceps intact, by flexion of the elbow.

Exercises.—These have been described in 42.

Elbow.—*Flexion.*—The muscles are: biceps; brachialis; brachioradialis; pronator teres; flexors of wrist and fingers; extensors of wrist and fingers (in pronation).

(The biceps should be regarded as a flexor supinator and the pronator teres as a flexor pronator. If there is weakness of the biceps it is extremely difficult to flex the elbow without pronating the hand, although normally the elbow can be flexed with the forearm either in pronation or supination.)

Examination.—43. The patient sits and bends the elbow until the hand touches the shoulder, while the surgeon offers resistance against the wrist. This movement should be done first with the hand in complete pronation, then with the hand in complete supination, in order to try out the different muscles taking part in it. If the weight of the arm cannot be raised gravity must be eliminated.

44. The patient lies on the affected side, with the arm straight, and flexes the elbow until the hand touches the shoulder, first in pronation, then in supination. No response in this position must be set down to complete paralysis of all the muscles involved.

It is important to find out what proportion of elbow flexor power is due to the biceps, as a favorable prognosis depends on the hope of getting back power in that muscle. The other elbow flexors can lift the weight of the arm when the

biceps is completely paralyzed, but can do very little more. Biceps paralysis is usually accompanied by pronation contracture.

Exercises.—150. As described in 43, (*a*) with resistance, (*b*) unaided.

151. As described in 44, (*a*) with resistance, (*b*) unaided, (*c*) with assistance. (To exercise the biceps the forearm must be supinated.)

152. The patient lies on his back, the upper arm supported vertically and flexes the elbow while the surgeon resists the movement.

Extension of the Elbow.—Triceps; anconeus; extensors of wrist and fingers (in supination) (Cunningham, not Piersol or Beevor).

Examination.—45. The patient sits with the upper arm raised forward as far above the shoulder height as possible and supported in that position, the elbow is completely flexed so that the hand touches the shoulder. He then extends the forearm against resistance on the wrist. (See Fig. 105.)

If the muscles cannot raise the weight of the arm, gravity must be thrown out of play.

46. The patient lies on the affected side, with the elbow flexed and the hand touching the shoulder, and tries to extend the forearm.

If this movement cannot be performed the muscles are paralyzed.

Exercises.—153. The patient lies on his back with the upper arm vertical and the elbow flexed and attempts to extend the elbow, (*a*) with resistance, (*b*) unaided against the weight of the arm above.

154. The patient sits with the forearm held up in flexion by the surgeon and attempts to extend the elbow. The surgeon makes such resistance at the wrist as may be necessary to neutralize the weight of the forearm and offering weak resistance if it can be overcome.

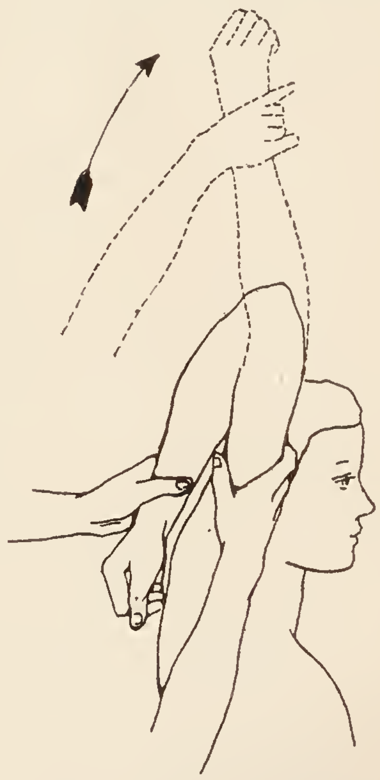

FIG. 105.—Examination No. 45, extension of the elbow.

SHOULDER

In the analysis of movements of the upper extremity so far given Cunningham, Piersol and Beevor have been consulted as the authorities and their divergent views given when they were different. In analyzing the extremely complicated movements of the shoulder Beevor's very complete study of this region will be followed, and his terminology of muscles and movements will in this section be adopted, and the others quoted only occasionally. In practice the method founded on Beevor's views has proved most satisfactory.

Movements of the Shoulder-joint.—*Advancing or flexion of the humerus to the horizontal line,* antero-posterior plane (raising the arm forward): deltoid (anterior); pectoralis major (clavicular); biceps; coraco-brachialis (?).

Advancing or flexion of the humerus above the horizontal line: serratus magnus; trapezius (acromial); trapezius (inferior).

The first set of muscles contract and carry the humerus forward nearly to the horizontal line, an action which would rotate the scapular downward and push the inferior angle toward the spinal column if the trapezius did not immediately contract to fix the scapula. The serratus magnus probably does not contract at the beginning of the movement, but comes to the aid of the other muscles as the humerus approaches the horizontal line. If the trapezius is paralyzed, the inferior angle of the scapula will first be drawn toward the spine as the arm is raised, but when the humerus has passed through about 45 degrees, the serratus will start contracting and rotate the scapula upward. There is apparently a definite order in which the separate muscles taking part in any given movement enter into action.

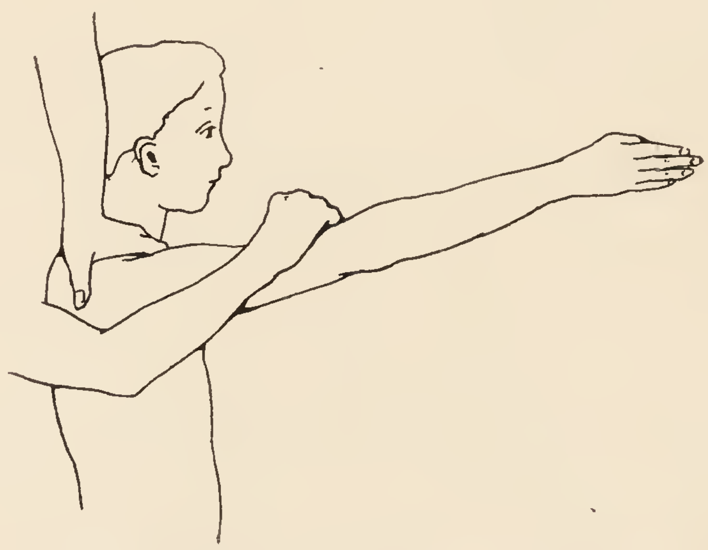

FIG. 106.—Examination No. 49, advancing or flexion of the humerus.

Examination.—47. The patient lies on the face, with the arms stretched forward above the head, and raises the arms from the table without raising the body. If all the muscles enumerated above are normal the patient will be able to raise the arms somewhat above the line of the body while the shoulders are kept in contact with the table, and will be able at the same time to overcome some resistance. If the arms cannot be brought up to a line with the body, there is either some muscular weakness or joint contracture or both.

48. The patient stands or sits, and raises the arm forward and upward against resistance on the front of the elbow.

49. The patient raises the arm forward while the surgeon fixes the shoulder girdle by pressing firmly down between the patient's neck and the point of his shoulder. (See Fig. 106.)

In test 48 all the muscles concerned in this movement act. In 49 the serratus magnus and trapezius are thrown out of action, and only those muscles act which advance the shoulder to the horizontal. By comparison of the two tests the relative weakening of the two sets of muscles is shown.

All the tests of this movement are to be used primarily to ascertain the condition of the trapezius and serratus magnus.

Abduction of the humerus to the horizontal line, latero-vertical plane: deltoid (middle); supraspinatus; biceps.

Abduction of the humerus above the horizontal line (raising the arm from the side): seratus magnus; trapezius (acromial); trapezius (inferior).

If the deltoid is paralyzed the trapezius and serratus will begin to act at once when the patient attempts to raise the arm sideways, and the inferior angle of the scapula will be seen to move outward, but the arm will be carried no more than 45 degrees from the side. To eliminate the action of the trapezius and serratus magnus the surgeon should fix the patient's shoulder girdle by downward pressure so that movement cannot take place above the horizontal.

Examination.—50. The patient stands or sits, and raises the arm straight sideways to shoulder height, against resistance. The arm should not be allowed to

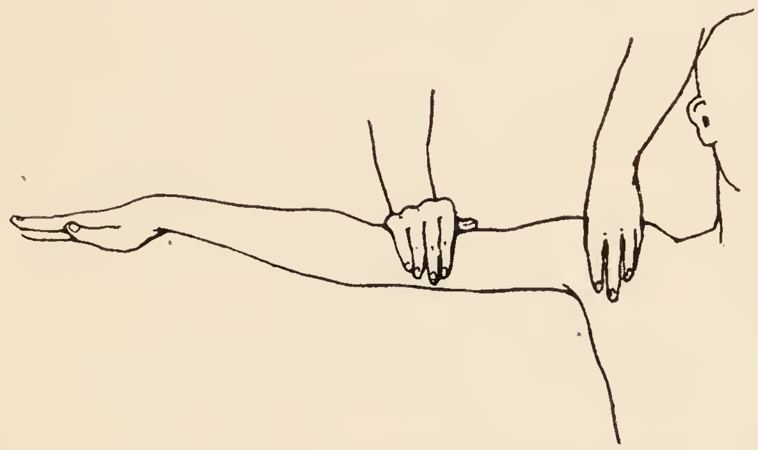

FIG. 107.—Examination No. 50, abduction of the humerus.

rotate outward, and the palm should be directed downward, as in this position the action of the biceps is excluded as much as possible from the movement. A normal deltoid can overcome considerable resistance besides the weight of the arm. (See Fig. 107.)

51. The patient lies on the back or on the face, and moves the arm out from the side to shoulder height. The same care is to be taken as in the previous test for position of the hand and fixation of the shoulder girdle. If the test is given with the patient lying on his back the greater part of the work is done by the anterior fibers of the deltoid; if on his face, by the posterior. It may well be that either half may show power while the other is totally paralyzed.[1] If the muscle does not functionate at all in this position it may not be totally paralyzed, on account of friction, but is certainly extremely weak.

A more delicate test can be made by slinging the arm under the elbow with a piece of bandage held far enough above so that the patient's movement is not assisted by it, but the friction of the arm on the table surface is removed.

Exercises.—155. The patient sits erect and with the arm at the side and raises the arm sideways until it is vertically above the head with the precautions described in 50, (*a*) with resistance, (*b*) raising the weight of the arm without resistance.

156. As described in 51, (*a*) with resistance, (*b*) unaided, (*c*) by means of a sling.

[1] R. W. Lovett: Jour. A. M. A., Mar. 4, 1916.

Extension of the humerus, antero-posterior plane (bringing the arm downward and forward): pectoralis major (sternal); latissimus dorsi; teres major and minor; infraspinatus; triceps (long head); subscapularis (?).

Hyperextension of the humerus (carrying the arm back of the body): latissimus dorsi; teres major and minor; infraspinatus; deltoid (posterior half).

During both parts of this movement the scapula is fixed by the rhomboids, the lowest fibers of the trapezius, and the pectoralis minor.

Examination.—52. The patient stands or sits with the arm in a vertical position above the head, and brings the arm forcibly forward and downward until it is in line with the body, while the surgeon offers resistance against the back of the arm just above the elbow. He must judge by the amount of resistance they can overcome whether or not the muscles are normal. Beevor is of the opinion that the clavicular portion of the pectoralis major, which is properly a flexor of the humerus, does not act in this movement, although it is in an anatomical position to do so.

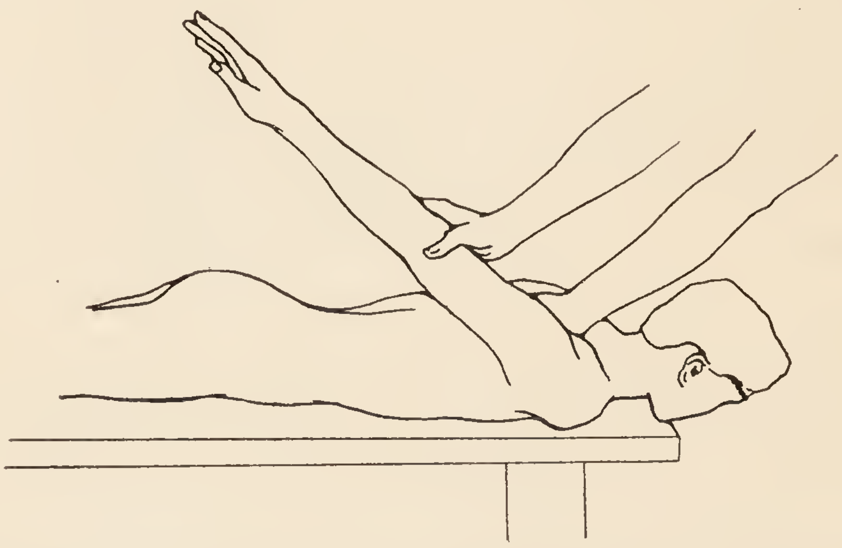

FIG. 108.—Examination No. 54, hyperextension of humerus.

53. The patient stands or sits with the arm hanging at the side and raises it backward as far as possible, while the surgeon resists on the back of the arm as before. The pectoralis major no longer acts, but the pectoralis minor may be felt contracting beneath it. This test is a means of distinguishing between their action.

54. The patient lies on the face with the arm at the side and raises it backward with resistance. This is an even more powerful test for the latissimus dorsi and posterior half of the deltoid. It is impossible to isolate the action of the latissimus dorsi, but some idea of its relative share in this movement may be obtained by feeling the muscle during the effort to contract. (See Fig. 108.)

Exercises.—The exercises are the same as the examination.

Adduction of the humerus, latero-vertical plane (bringing the arm to the side): pectoralis major (all); latissimus dorsi; teres major and minor; infraspinatus; subscapularis (?); deltoid (posterior third).

As in the previous movement the rhomboids and the lowest fibres of the trapezius fix the scapula. When they are paralyzed and the arm

is forcibly brought down to the side, the inferior angle of the scapula is drawn outward away from the spine. When they are normal and the adductors are paralyzed an attempt to adduct brings the inferior angle of the scapula toward the spine.

Examination.—55. The patient stands or sits and pulls the arm down to the side against resistance under the elbow.

Whether or not the muscles are normal must be judged by the amount of resistance they can overcome and by the hardening of the tendons, which are easily felt at the anterior and posterior borders of the axilla.

56 The patient lies on the back or on the face, with the arm stretched sideways at right angles to the body, and draws the arm in to the side.

The position on the back shows up the pectoralis best, that on the face, the latissimus. If the muscles are too weak to overcome the resistance of the arm on the table the arm may be slung as in the deltoid test. If there is then no sign of function the muscles must be classed as totally paralyzed.

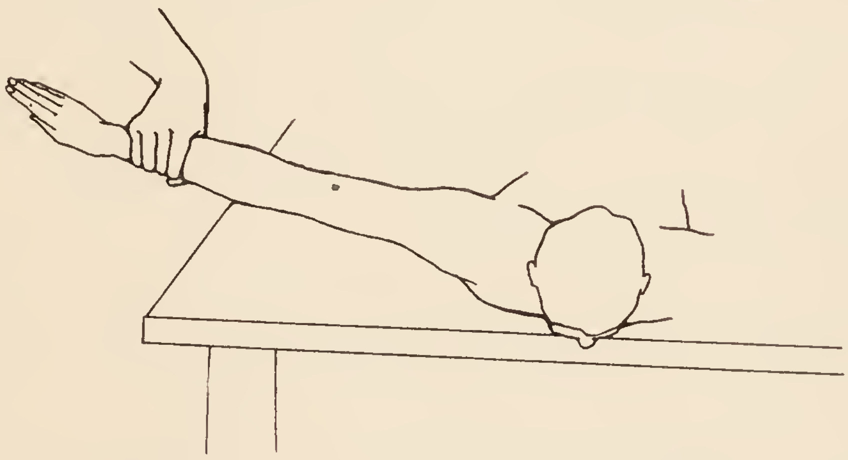

FIG. 109.—Examination No. 59, horizontal abduction of humerus.

Exercises.—157. The patient performs 55.

158. The patient lies on the back with the arm stretched above the head and brings it to the side, (*a*) with resistance, (*b*) unaided, (*c*) with the aid of a sling to remove friction.

Horizontal adduction of the humerus (bringing the arm toward the middle line of the body at shoulder level): coraco-brachialis; pectoralis major; deltoid (anterior half).

Examination.—57. The patient lies on the back with the arms stretched out sideways at shoulder height, elbows straight, palms up and raises the arms toward the middle line of the body until they are vertical and the palms meet above against resistance.

The deltoid does not take part in this movement to any considerable extent, so that it is as pure a test as can be found for the pectoralis major.

58. The patient sits with the affected side toward the table, upon which the arm is supported at shoulder height, and tries to slide the arm forward along the table.

Exercises.—159. See 57, (*a*) with and (*b*) without resistance.

160. See 58, (*a*) with resistance, (*b*) unaided, (*c*) with a sling.

Horizontal abduction of the humerus (carrying the arm back at shoulder level): deltoid (middle); deltoid (posterior); latissimus dorsi; teres major and minor; infraspinatus; subscapularis (?).

In this movement the middle fibers of the trapezius fix the scapula.

Examination.—59. The patient lies on the face with the arm stretched sideways at right angles to the body, and raises the arm straight up from the table, with resistance from the surgeon. (See Fig. 109.)

If the deltoid is normal and the trapezius paralyzed the arm will be raised from the table, but the point of the shoulder will be pushed forcibly against the table and used for a pivot. If the condition is reversed the scapula will be drawn toward the spine and the point of the shoulder raised from the table with the arm dragging down.

60. The patient sits facing the table with the arm resting on it in a position of extreme adduction, that is, crossed over to the other side, and tries to abduct the arm.

Exercises.—161. The same as 59, (*a*) with resistance, (*b*) without.

162. See 60, (*a*) with resistance, (*b*) unaided, (*c*) with a sling.

Inward rotation of the humerus (twisting the arm in): pectoralis major; deltoid (anterior); teres major; latissimus dorsi; subscapularis.

Outward rotation of the humerus (twisting the arm out): teres minor; infraspinatus; deltoid (posterior).

Examination.—61. The patient lies on the face with the arm stretched out sideways at shoulder height, the forearm and hand hanging down over the edge of

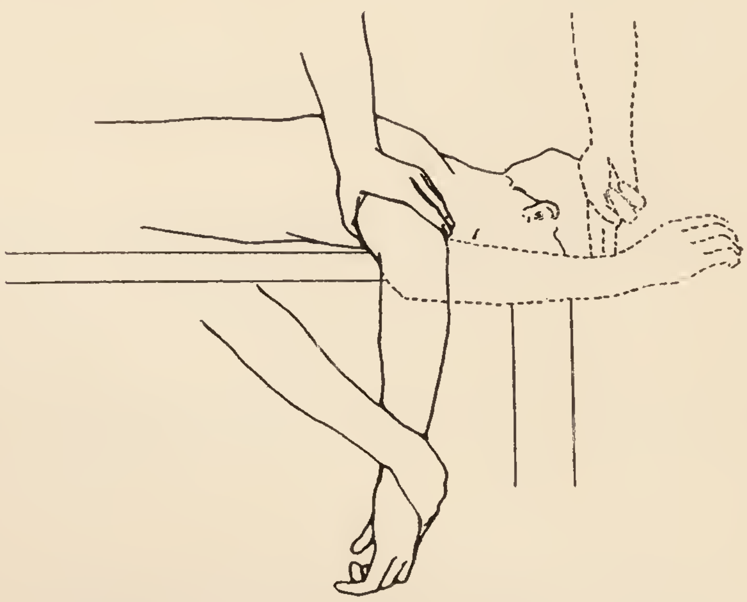

FIG. 110.—Examination No. 61, outward rotation of humerus.

the table, so that the elbow is bent at a right angle. The surgeon steadies the upper arm and offers resistance against the ulnar side of the wrist while the patient raises the hand backward and upward, thus rotating the humerus *inward;* the surgeon then offers resistance against the radial side of the wrist while the patient raises the hand forward and upward, thus rotating the humerus *outward*. (See Fig. 110.)

The outward rotators, teres minor and infraspinatus, can easily be felt to contract by placing the fingers just below the spine of the scapula. They are assisted by the posterior fibers of the deltoid, the condition of which must be

taken into account. Even normal muscles can overcome only very slight resistance in these movements, as the leverage is very great.

62. The patient lies on the back, the arm close to the side, the elbow bent at a right angle and the forearm resting across the body. He turns the arm outward, pivoting it on the elbow, which is kept at a right angle and then turns it in again. The first movement is a test for weak *outward* rotators, the second a test for weak *inward* rotators.

Exercises.—The exercises are the same as the tests described (61 and 62).

Elevation of the Shoulder.—The muscles are: trapezius; levator anguli scapulæ; rhomboids.

Examination.—63. The patient sits and shrugs the shoulder while the surgeon offers resistance by pressing down from above.

NECK[1]

Flexion of Head.—Sterno-mastoids (Piersol); omo-hyoids; sterno-hyoids; sterno-thyroids; mylo-hyoids; recti capitis antici, longus colli, other smaller muscles.

Examination.—64. The patient lies on the back, with the shoulders held down, and attempts to raise the head from the table.

The sterno-mastoids are important muscles concerned in this movement. When they are seriously weakened the other muscles are apparently not strong enough to lift the head.

65. The patient sits with the head hanging over backward and raises it to the vertical. This can probably be done without the sterno-mastoids. The exercises are the same as the tests (*a*) with resistance, (*b*) without.

Extension of Head.—Trapezii (clavicular) (Piersol); splenii capitis; recti capitis postici; obliqui inferiores and others.

Examination.—66. The patient lies on the face, shoulders held down, and raises the head against resistance on the back of the head.

The **exercise** is the same as the examination.

Lateral Flexion of the Head.—

Examination.—Many muscles take part in the movement, the sterno-mastoid being perhaps the most important.

67. The patient lies on the unaffected side and attempts to raise the head laterally, (*a*) with resistance, (*b*) without.

The **exercise** is the same as the examination.

Rotation of the Head.—

Examination.—A very complicated movement shared by many muscles.

68. The patient sits with the face turned to one side and rotates the head to the opposite side against resistance.

The **exercise** is the same as the examination.

[1] In the neck movements many muscles are involved and there is only partial agreement among anatomists as to their particular function. The list of muscles therefore given in this connection is of little value.

CHAPTER VII

THE SPRING BALANCE MUSCLE TEST

At the time when the first series of Vermont observations was taken in January, 1915, the examination of paralyzed and partly paralyzed muscles was made wholly by hand and it became evident at once that some quantitative method of estimating muscular strength was necessary for any accurate study or any conclusions of value to be drawn from such study.

By manual examination the muscles could only be classed as normal, partly paralyzed or totally paralyzed. The first and the last class were clear enough, but in the "partly paralyzed" division we had to group muscles which were just short of normal and muscles which showed only a flicker of movement on attempted contraction. Between these two widely separated conditions existed every degree of disability, yet one must put them all in one class. Exact study of the phenomena under these conditions was impossible.

Again, in the matter of treatment some scale of measuring improvement or the reverse was urgently needed. "Impressions" that electricity of one kind or another, or rest or exercise were beneficial have filled literature; unsupported assertions, marvelous cures, fantastic treatments have too often been advanced on the slenderest of grounds. With the realization that partial paralysis was the usual form of affection, it became imperative to have some scale by which to work out what should be a precise and more accurate treatment. The muscle test to be described offers a practical quantitative scale by which the effects of modifications of treatment may be studied week by week and month by month.

The problem was presented to Professor Cannon and Assistant Professor Martin of the Physiological Department of the Harvard Medical School and the latter worked out a system of muscular tests by means of the spring balance, which have proved reliable in practical use and which have been published.[1]

[1] E. G. Martin and R. W. Lovett: "A Method of Testing Muscular Strength in Infantile Paralysis," "Jour. A. M. A.," Oct. 30, 1915.

R. W. Lovett: "The Treatment of Infantile Paralysis. The Newer Aspects of the Problem with Certain Conclusions Drawn from the Vermont Epidemic," "Jour. A. M. A.," June 26, 1915.

R. W. Lovett and E. G. Martin: "Infantile Paralysis in Vermont. A Report of the Progress of Cases Between January, 1915, and July, 1915," "Vermont State Medical Journal," February, 1916.

R. W. Lovett and E. G. Martin: "Certain Aspects of Infantile Paralysis, with a Description of a Method of Muscle Testing," "Jour. A. M. A.," Mar. 4, 1916.

R. W. Lovett and E. G. Martin: "The Muscle Test for Infantile Paralysis—a Description of the Technique," "Am. Journ. Orth. Surg.," July, 1916.

The method of testing was first tried out in the spring of 1915 and was far enough advanced to be used in Vermont in the summer and autumn of 1915 by Professor Martin. By the spring of 1916 there had accumulated 13,000 observations in 400 series on 177 patients which have been published. The technique of the test will first be described.

TECHNIQUE OF THE MUSCLE TEST

It is designed to test, under conditions of constant position and leverage, by a series of spring balance pulls, the power of the muscles which govern the movement of the limbs. The value of the test consists in the possibility of duplicating exactly the conditions of the first test at succeeding ones so that a definite idea of gain or loss in muscular strength can be registered in pounds. It is applicable for all tests of power in normal muscles, for determining loss or gain in power at stated intervals, for the determination of the degree of initial weakness in paralyzed muscles, for determining the relative strength of the different muscles before tendon transplantation and similar operations. It has been applied for one year in consecutive tests varying in frequency from ten days to three months to infantile paralysis cases. The result has been an accurate register of general gain and occasional loss in the cases under treatment. The record has the advantage of representing concisely, in figures, the results of detailed muscular examination, and of presenting at later examinations the initial and intermediate conditions of the case.

The method aims at pulling against a fixed position assumed by the patient rather than attempting to have the patient initiate a movement because it was found with children that they would hold a fixed position much more readily than they would initiate a muscular movement.

The accuracy of the test depends upon the training of two persons, an operator and an assistant to coördinate the pull of the muscle and the registration of the pull on the scales, and upon the maintenance with exactness of the positions and leverage relationships outlined individually below. Accurate spring balance scales (No. 5) are used of four sizes: 1 to 4 lb., graded in ounces; 1 to 30 lb.; 1 to 50 lb.; and 1 to 100 lb. The readings are taken to the half pound except on the ounce scale. The operator in general controls and maintains the correct position of the subject, stimulates the subject to innervation, braces and guides the limb tested, and calls the moment of give in the muscle tested through watching the action of the muscle itself. The assistant makes the pull along lines accurately determined, beginning and stopping under the direction of the operator. The same command directs the muscular pull of the patient and the scale pull of the assistant. In all cases where the position of the assistant makes this possible, the scale reading is taken by him at the moment when the yielding in the muscle is called by the operator.

Except under special circumstances, plantar flexion is the only reading which the operator is required to make.

Twenty-two readings are taken, for each of which the best position of the subject for the accurate reading of the scales and for constant leverage in limb action has been determined experimentally. The order in which muscles are tested is immaterial except under conditions of weakness, but it is best that the order be constant so that all tests duplicate each other as completely as possible. The apparatus required is shown in the illustration (Fig. 111) and referred to by the number on each piece, as they come into use in the description of the measurements themselves.

In the **lower extremity,** the test records the following movements: plantar flexion, dorsiflexion, inversion, eversion, adduction, abduction,

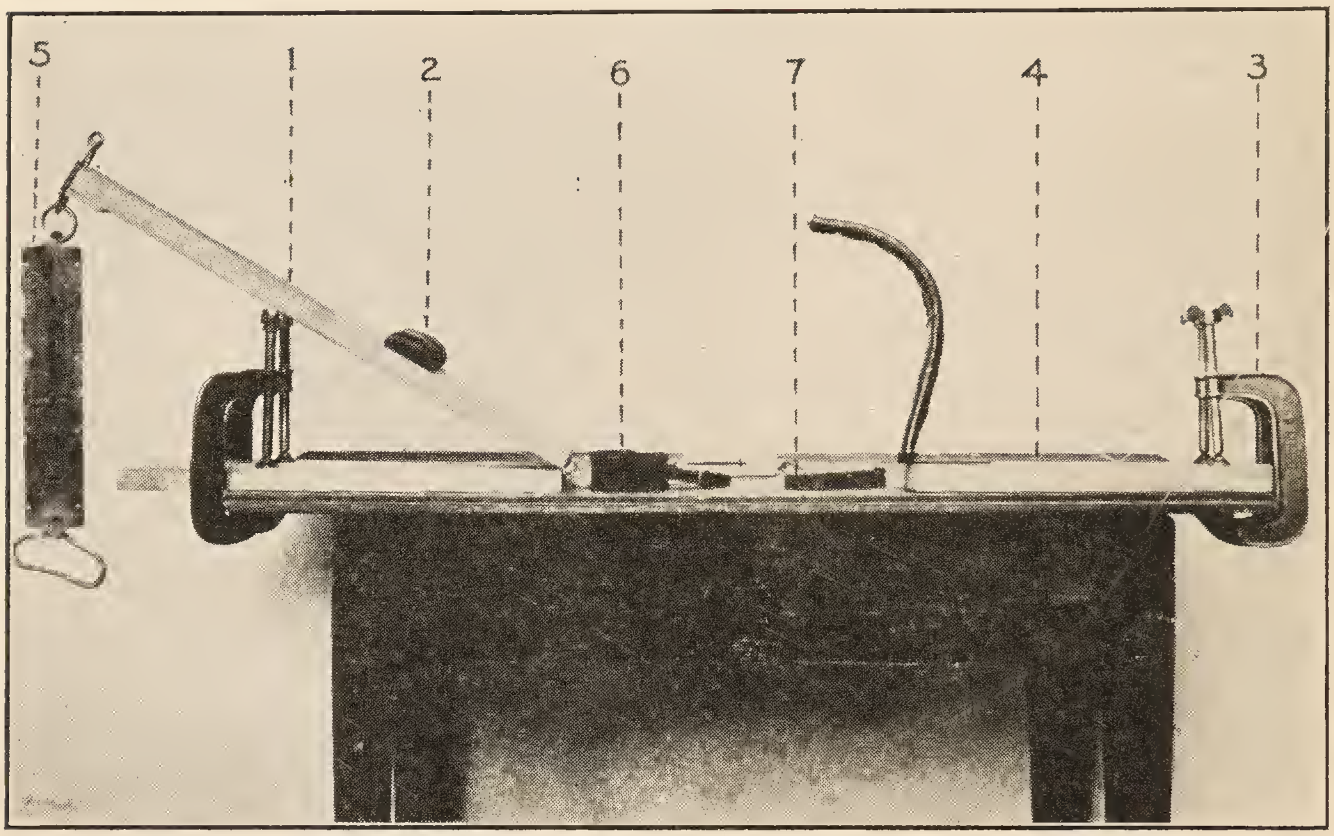

FIG. 111.—Table and apparatus for use in muscle testing. The numbers are referred to in the text.

hip extension, hip flexion, knee extension, knee flexion. The position of the operator and assistant in each movement is determined by their own convenience for fulfilling the other conditions of the test. The operations of these two individuals and the position and action required of the subject, for the measurement of these movements, are as follows:

Plantar Flexion.—The subject lies on his back on a smooth table. The foot is braced against a three to one lever (No. 1). The scale hook is inserted in the ring of the lever upright. The lever must be adjusted so that the ball of the foot in maximum plantar flexion rests squarely upon the lever pad (No. 2), with the upright at an angle of from 60 to 80 degrees to the table. The lever is held in position by C-clamps (No. 3). The pull is made by the assistant from the head of the table with the scale horizontal

and in line with the leg being tested, and is increased in intensity to the point where the muscular resistance is overcome. To prevent slipping on the table, the shoulders of the subject are held by the hip-braces (No. 4). The muscle gives at about 45 degrees of plantar flexion with a rather sharp break in the resistance offered to the spring balance. All measurements of degrees are made to the plane of the table unless otherwise specified. The operator guides the position of the foot, stimulates the patient to innervation, and calls the moment of break in the muscle to the assistant for reading or reads the scale himself. The reading of the scale must be simultaneous with this break.

Dorsal Flexion.—The general position of the subject is the same. The foot should be flush with the end of the table to give freedom of action to

FIG. 112.—Muscle test for dorsal flexion of foot.

the assistant in making the pull, and should be slightly lifted and braced by the hands of the operator which encircle the ankle. The leather loop (No. 6) is placed across the toes at their metatarsophalangeal joints. With the foot in maximum dorsiflexion, the assistant makes the pull at right angles to the plantar surface of the foot, lowering the scale to maintain this angle as the foot gives. The muscle is watched by the operator and the moment when it gives called to the assistant who takes the scale reading. (Fig. 112.)

Inversion.—Body position of the subject, the same as in dorsal flexion. The loop is across the inner surface of the great toe joint. The ankle is braced by the hands of the operator. With the foot at right angles to the leg, the foot is inverted and adducted as far as possible without inward rotation of the leg. The pull is opposite in direction to the muscular con-

traction, horizontal, and in the same vertical plane as the foot. The assistant swings the scale so as to maintain this relationship as the foot gives. The reading is taken by the assistant at the moment when the operator calls the break in resistance of the foot.

Eversion.—General position as in dorsal flexion. Loop at the outer surface of the distal end of the fifth metatarsal. The foot is at right angles to the leg and is everted and abducted as far as possible without outward rotation of the leg. The pull is horizontal and in the same vertical plane as the foot with a scale swing to maintain this position. The break is called and read as above.

Adduction of the Leg.—No change in general body position of the subject. Two hip-braces (No. 4) are placed in line with the crest of the ilium on each side of the pelvis and attached to the table with the C-clamps. With one hand in the popliteal space and the other below the heel, the operator gently supports the weight of the leg, raises the leg about 15 degrees from the table, and maintains the foot vertical to prevent leg rotation. The subject contracts the inner muscles of the thigh so as to swing the leg inward across the median line about 15 or 20 degrees. This angle of contraction is a matter of comfort to the subject and varies with the individual. The angle of elevation of the leg from the table must be constant. The subject, during the pull, braces the trunk with the hands by pushing against the clamps of the hip-brace on the side opposite to that being tested. The loop is placed just above the internal malleolus. The pull is outward, horizontal, and at right angles to the leg. It must swing so as to preserve this angle as the leg gives. The operator calls for the reading as the leg becomes exactly parallel to the median plane of the body. This reading can be taken in the same fashion with the loop at the knee just above the patella. The power here, with allowance for the minor individual variations in leg length, doubles the ankle pull through halving the distance of the measuring spring balance from the fulcrum. The knee pull is used where the quadriceps is weak and it is difficult for the subject to maintain knee extension while making the adductor pull from the hip.

Abduction of the Leg.—The details of position and bracing in this pull differ only in the direction of the muscular action which reverses the bracing and the positions of the operator and assistant. The loop is just above the external malleolus. The subject contracts the muscles which abduct the hip so as to swing the leg outward from the median plane at an angle of 30 or 40 degrees, according to individual comfort. The pull is inward, horizontal and at right angles to the leg. This angle and the angle of 15 degrees of leg elevation must be maintained constant throughout the pull, exactly as in adduction. The operator calls for the scale reading as the leg becomes parallel to the median plane. The test is made at the knee where the quadriceps is weak.

Hip Extension.—The subject lies on the side opposite to that to be tested with the hips directly one above the other. The abdomen is braced against the hip-clamp used in abduction and adduction. At the lower end of the table, two C-clamps, across which a small board is placed for comfort, are used by the subject as a brace. He pushes against this with the foot of the leg not being tested to secure steadiness. The trunk is braced forward, by the subject, by holding to the edge of the table with the hands. The operator maintains the position of the abdomen against the hip-brace with one hand and with the other supports the weight of the leg to be tested and keeps the leg parallel to the table. The loop is at the knee across the popliteal space. The leg is placed in maximum extension with the knee straight. The direction of pull of the balance is slightly less than 90 degrees to the leg, being deflected toward the trunk, and is exerted horizontally. The angle of the pull must be constant throughout the movement. The operator calls for the reading as the leg crosses the line of the trunk, or if the muscle gives before this, the reading is taken when the muscle yields.

Hip Flexion.—Side position and foot-brace as for hip extension. The small of the back is against the hip-brace. The subject maintains the rigidity of the trunk by pushing with the hands against the opposite hip-brace. The operator supports the leg parallel to the table with one hand at the knee and the other at the ankle. The loop is at the knee just above the patella. The knee is well bent, and the thigh is flexed above the right angle. The pull is horizontal and as near as possible at right angles to the femur. The reading is taken when the muscle gives.

Knee Extension.—The subject lies on the face on the table with the lower leg flexed at the knee and vertical to the table. The loop is at the ankle just proximal to the malleoli. The assistant stands at the head of the subject bracing the shoulder with one hand. The pull is horizontal and parallel to the median plane. The operator braces the knee on the table with one hand and with the other at the ankle limits the extension. The movement begins from the perpendicular position, and the effort of the subject to extend the leg and the pull of the assistant must start simultaneously at the command of the operator. Both pulls should begin slowly, and it is essential that the muscle pull and the pull of the spring balance should develop together in this test. The leg is not permitted to extend from the perpendicular position further than to within 75 degrees of the table. Greater extension than this changes the leverage and produces inaccuracy. The pull of the assistant continues until the knee is drawn back to the original position, the operator calling for the scale reading exactly as the leg crosses the perpendicular line. The quadriceps test is the most accurate of all tests to repetition, but also the most liable to error if over-extension is permitted before the balance pull begins to draw the leg back to the vertical position (Fig. 113).

Knee Flexion.—General body position of the subject and brace by the operator the same. Ankle loop reversed in direction and assistant at the foot of the table. The subject places the leg in maximum flexion. The pull is horizontal and rotation of the hip should be minimized. The operator calls for the scale reading as the leg passes the perpendicular position. If the reading is taken with the leg more than 15 degrees beyond the perpendicular, accuracy is destroyed through change of leverage.

This group of leg tests can be made in half an hour where the subject responds easily to directions and the operator and assistant are accustomed to coördinate work. Every reading is repeated as a check. The readings agree very closely unless there is an error in technique. In the first test

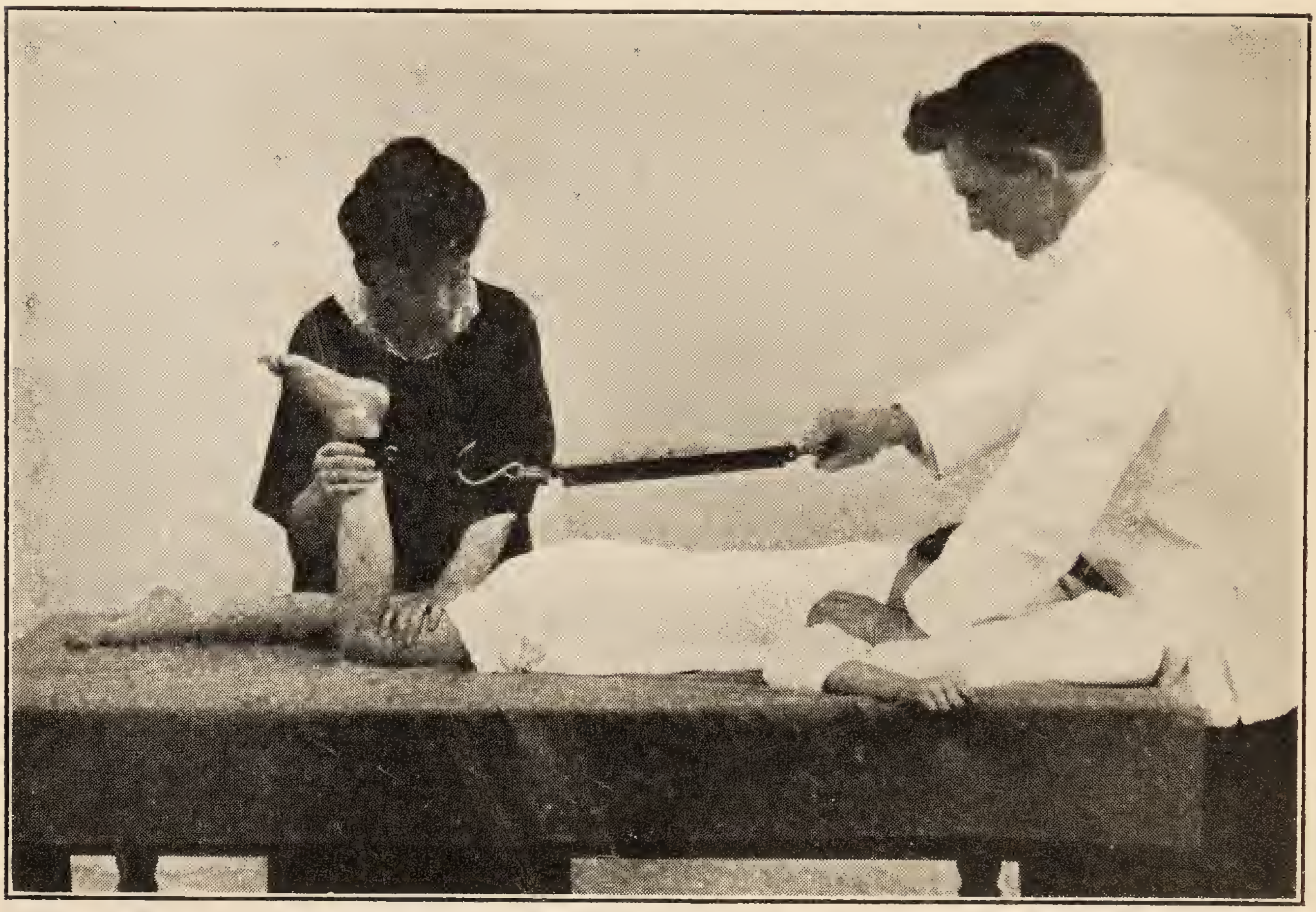

FIG. 113.—Muscle test for knee extensors.

the pull generally rises slightly on the repetition because the subject understands the requirements of the movement better the second time it is made. But in subsequent tests, the first reading is usually the better.

In the **upper extremity** the test records the following movements: Pectoralis, latissimus dorsi, anterior deltoid, posterior deltoid, forearm extension, forearm flexion, wrist extension, wrist flexion, finger extension, finger flexion, thumb adduction, thumb abduction. In all the movements, the break is called by the operator and the scale read by the assistant. For the first four movements the loop is at the elbow just above condyles of the humerus.

Pectoralis.—The subject stands or sits with the shoulders and the hips in the same vertical plane. If standing, he braces the thigh well against the table to prevent loss of balance. The arm is drawn as far as possible

across the front of the body just clearing the trunk with the forearm in pronation. Any brace of the body with the opposite arm is permissible which does not disturb the plane of the shoulders and hips. The pull is horizontal and outward posteriorly at an angle of 30 degrees to the lateral plane of the body.

Latissimus dorsi.—The subject stands or sits as above. The fist is closed and with the dorsum of the hand toward the back, the arm is drawn as far as possible, across, behind the body, just clearing the trunk. The pull is horizontal and outward anteriorly at an angle of 30 degrees to the lateral plane.

Anterior Deltoid.—Positions of the subject, the same. The opposite hand holds to any support which does not elevate the shoulders. The arm being tested is raised to the level of the shoulder, and brought forward to an angle 30 degrees from the lateral plane of the trunk. The pull is backward and downward, establishing an angle of 60 degrees with the upper arm and maintains this angle as the arm gives.

Posterior Deltoid.—The subject stands or sits as in the other shoulder tests. The arm is raised to the level of the shoulder posteriorly at an angle of 30 degrees to the lateral plane of the trunk. The pull is forward and downward, establishing an angle of 60 degrees with the upper arm, and maintains this angle as the arm gives.

Forearm Extension.—The subject lies on the back with the arm at the side and the forearm perpendicular to the table against which the elbow rests. The hand is closed with the thumb pointing to the shoulder. The loop is at the wrist just proximal to the styloid process of the ulna. The assistant stands at the head of the table and braces with one hand the shoulder of the side to be tested. The operator braces the elbow on the table with one hand and with the other at the wrist limits the extension of the forearm. The pull is horizontal. At the direction of the operator, the extension of the forearm and the pull of the assistant start together slowly. Extension is permitted to from 5 to 15 degrees from the perpendicular and is overcome by the assistant. The call for the reading of the scale is made just as the forearm crosses the vertical line.

Forearm Flexion.—No change in the position of the subject nor the bracing of the operator. Loop just proximal to the styloid process of the radius. The forearm is placed in maximum flexion with the elbow on the table, the hand closed, and the thumb pointing toward the shoulder. When the muscular power requires it, the foot-brace described in hip extension is used in the same fashion by the subject to prevent slipping during the movement. The pull is horizontal. The operator calls for the scale reading as the forearm crosses the perpendicular line.

Wrist Extension.—The subject extends the entire arm laterally and anteriorly according to individual comfort. With the palmar surface of the hand vertical and the fingers extended, the wrist is put in maximum extension. The operator encircles the wrist with his hands, bracing the

subject's arm in the extended position. The small loop (No. 7) is across the dorsum of the hand just distal to the metacarpals. The pull is exerted horizontally and at an angle slightly less than 90 degrees to the hand, being deflected toward the wrist. The angle of pull must be constant and to secure this the assistant swings the scale through an arc as the hand gives. The accuracy of the reading depends absolutely upon maintaining the direction of the pull and upon the correct placing of the loop and is most important in this and the three following tests.

Wrist Flexion.—With the arm well away from the side, the subject flexes the elbow according to comfort. With the fingers flexed at right angles to the palm, and the palmar surface of the hand in the vertical plane, the subject puts the wrist in maximum flexion. The small loop is across the palm at the crease formed by the finger flexion. The operator braces the wrist and arm in this position, encircling the wrist with both hands. The pull is horizontal and at an angle slightly less than 90 degrees to the dorsal surface of the hand. The angle of the pull must be maintained by an arc swing of the scales.

Finger Extension.—The subject extends the arm as for wrist extension. The hip-brace is attached lengthwise to the side of the table. The palm of the hand well below the palmar crease is braced by the operator against the curved upright of the brace. The small loop is across the fingers dorsally just proximal to the first interphalangeal joint. The pull is horizontal and at an angle slightly less than 90 degrees to the extended fingers and deflects toward the wrist.

Finger Flexion.—The position of the subject and the brace by the operator are the same. The small loop is placed across the fingers on the palmar surface just proximal to the first interphalangeal joint. The palmar surface of the hand is vertical against the brace. The pull is horizontal and slightly less than 90 degrees to the proximal phalanges. The deflection is toward the dorsum of the hand.

Thumb Adduction.—With the palmar surface down and the hand horizontal, the operator braces the extended fingers with one hand and the wrist with the other. The small loop is placed at the interphalangeal joint of the thumb. The subject adducts the thumb as far as possible under the palm. The pull is horizontal and at right angles to the thumb. The call for the reading is made by the operator just as the thumb appears from under the hand.

Thumb Abduction.—General position of the hand and brace by the operator the same as for the preceding test. The subject abducts the thumb in the same horizontal plane as the hand. The position of the small loop is identical with that of adduction, but reversed in direction. The pull deflects downward from the horizontal just enough to escape the palmar surface of the hand. It is exerted at right angles to the thumb.

The complete arm test requires half an hour and each reading is repeated as a check.

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